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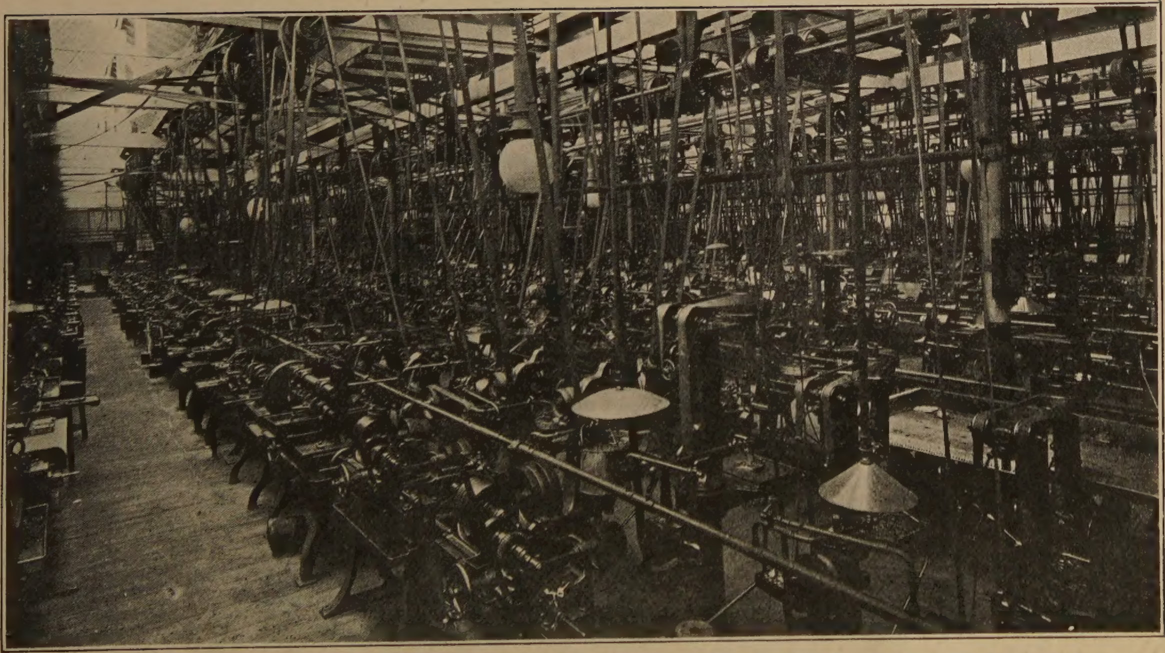

Machine Shop of the Birmingham Small Arms Co. Ltd.

MODERN WORKSHOP PRACTICE

A Manual

FOR THE USE OF ENGINEERS, APPRENTICES AND STUDENTS IN TECHNICAL INSTITUTES

BY

ERNEST PULL

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CHIEF INSTRUCTOR AND LECTURER TO MUNITION WORKERS, UNDER THE METROPOLITAN MUNITIONS COMMITTEE
LONDON COUNTY COUNCIL SCHOOL OF ENGINEERING AND NAVIGATION, POPLAR, E.

WITH 277 ILLUSTRATIONS AND 12 PHOTOGRAPHIC PLATES

Fifth Edition Revised and Enlarged

Capio Lumen

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1918

PREFACE

THIS book has been written in the hope that it may prove of service to young Engineers, Students in Technical Institutes, and Candidates for the Examination for entry into the Royal Navy as Engine Room Artificers. It should also be of use to those taking the City and Guilds Examination in Fitting and Turning.

The recent rapid increase in the number of Technical Institutes and Trade Schools has brought opportunities of systematic instruction in Workshop Practice within the reach of a very large body of students, and the aim of the author is to meet the requirements of this class by a general introduction to the entire subject, treated throughout in a concise and practical manner.

It is to be understood that the London County Council accept no responsibility for any opinions or conclusions appearing in this book.

E. P.

L.C.C. SCHOOL OF ENGINEERING AND
NAVIGATION, POPLAR, E.

PREFACE TO SECOND EDITION

THE fact that the first edition has been sold so soon after publication indicates that a demand exists for a book of this character.

Opportunity has been taken to make some minor corrections, and chapters have been added dealing with Gear Hobbing and Planing Machines, Turret and Capstan Lathes, Boring Mills, and other machines not previously dealt with.

Munition workers and persons taking up munition work should find this book particularly useful. A careful study of its contents will enable them to take a position in an engineering works with more confidence than they otherwise would do.

E. P.

L.C.C. School of Engineering and
Navigation, Poplar, E.

PREFACE TO FOURTH EDITION

The second and third editions having been disposed of within twelve months, the opportunity has been taken in this edition to add a chapter on "Modern Capstan and Turret Lathe Tools," and also to make a few alterations in the text.

The design and use of capstan and turret lathes have been developed and extended to a very considerable extent during the war, and it is probable that the advantages of these types of machines for rapid and accurate production of engineering work will result in their use, to a very great extent, after the war.

E. P.

L.C.C. School of Engineering and
Navigation, Poplar, E.

PREFACE TO FIFTH EDITION

In this edition a chapter on Tool-Holders has been added, and some of the matter has been revised, in order to bring the data into line with the latest and best practice.

The index has also been greatly enlarged and improved.

E. P.

L.C.C. School of Engineering and
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WORKSHOP PRACTICE FOR ENGINEERS

CHAPTER I

MEASUREMENTS AND SMALL TOOLS

THE unit of measurement in the United Kingdom is the Standard Imperial Yard. This was legalised by the British Government in 1855, and is generally adopted for all dimensions by English manufacturers.

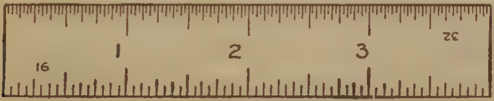


FIG. 1.—Steel Rule.

The **Standard Steel Rule**, Fig. 1, is made in various lengths, widths, and thicknesses, and can be obtained either of flexible or hardened steel. The graduations are made as fine as one hundred to one inch, but for most purposes a rule having graduations of 8, 16, 32, and 64 parts to the inch is most suitable.

For convenience in measuring short lengths in places inaccessible to the ordinary rule, a good method is shown in Fig. 2. It consists of a tool holder constructed with a knurled handle and a split chuck, which can be adjusted by means of a nut at the top of the barrel, the arrangement allowing for any size of rule to be set at the required angle.

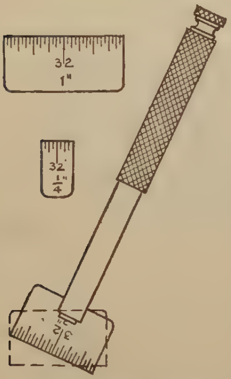


FIG. 2.—Rule Holder.

Calipers.—Calipers are made in very large variety, some having adjustments for taking sizes very accurately. The caliper does not act as a measuring tool, but is simply a gauge, the actual size being taken from it by means of the rule. To obtain the size or diameter of a piece of work the caliper should be held near the joint, and kept at right angles to the work and adjusted to the sense of touch, the accuracy of measurement depending upon the skill of the user. A good pair of ordinary type of calipers should work smoothly when opened and closed, without the slightest jerk.

For taking the diameter of the outside of threaded work, calipers with wide points are used, as shown in Fig. 3. For general gauging the points are as shown in Fig. 4. Inside calipers for internal gauging are shown in Fig. 5.

Dividers are made in similar forms to inside calipers, and are used for scribing circumferences and areas. One type of divider is shown in Fig. 6. The points of dividers should always be hardened and tempered to prevent them becoming blunt or bent during use.

Thickness Gauge.—A most useful tool for fine

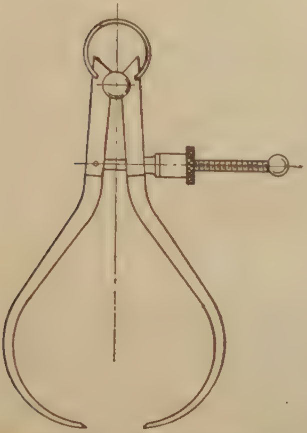


FIG. 3.—Thread Calipers.

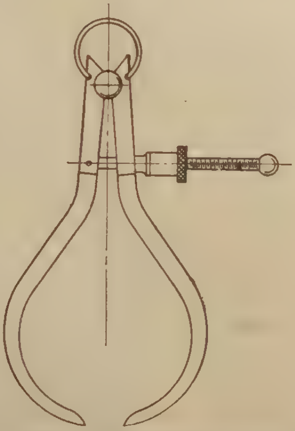


FIG. 4.—Outside Calipers.

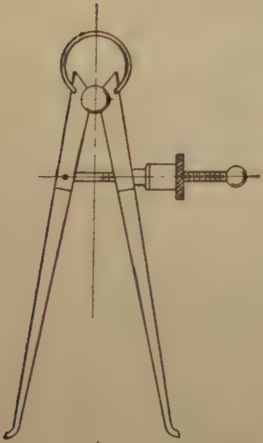


FIG. 5.—Inside Calipers.

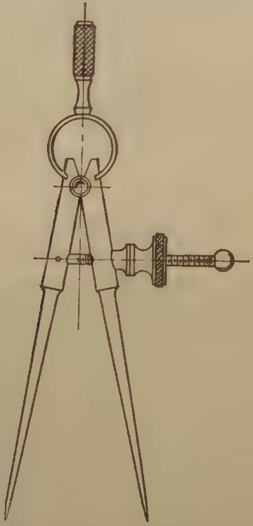


FIG. 6.—Dividers.

measurements is the thickness or feeler gauge, Fig. 7. The blades are made from strips of flexible metal of known thickness, the actual thickness being stamped on each strip. They can be used singly or collectively. For obtaining the clearances of bearings, or the distance between two surfaces, they are of special use.

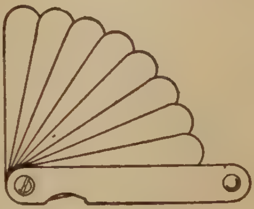


Fig. 7.—Thickness Gauge.

Bevel Gauge.—For obtaining angles several types of bevel protractors are made. By means of these tools the angle can be read direct from the protractor. A simple form of bevel gauge or square is shown in Fig. 8. This is a common workshop tool used by fitters and machinists for marking off angles on work, but it must be first set by means of a protractor.

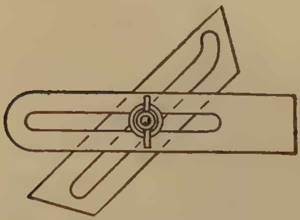


Fig. 8.—Bevel Gauge.

A universal bevel protractor, with a vernier attachment, is shown at Fig. 8A. It consists of a graduated disc with a fitted blade and adjustable stock. Any given angle may be laid off or measured by setting the stock at the angle shown by the graduated disc. The disc of the protractor is graduated in degrees from 0° to 90° each way. The vernier plate is graduated so that 12 divisions on the vernier occupy the same space as 23 divisions on the disc. The difference between the width of one of the 12 spaces of the vernier and two of the 23 spaces on the disc is therefore $\frac{1}{12}$ of the space on the disc. Each space on the vernier is $\frac{1}{12}$ of a degree, or five minutes shorter than two spaces on the disc. If a line on the vernier coincides with a line on the disc and the protractor is rotated until the next line on the vernier coincides with the next line on the disc, the vernier has been moved through an arc of $\frac{1}{12}$ of a degree, or 5′. To read the protractor, note on the disc the numbers of whole degrees between 0 on the disc and 0 on the vernier. Then count in the same direction the number of spaces from 0 on the vernier to a line that coincides with a line on the disc. Multiply this number by 5 and the product will be the number of minutes to be added to the number of the whole degrees.

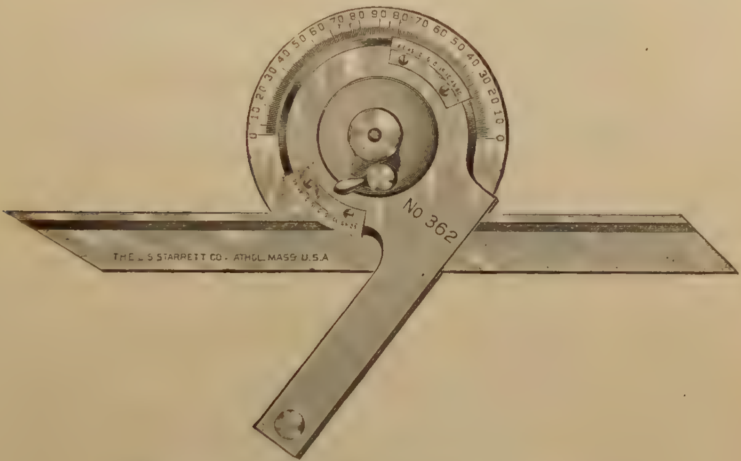


FIG. 8A.—Universal Bevel Protractor, with Vernier.

Scribers.—Two forms of scribers are shown in Fig. 9. They are made from carbon steel with hardened points, and are used for scratching or marking metal. The bent form of scriber is used in marking out work where there is not sufficient room for the straight scriber to be used.

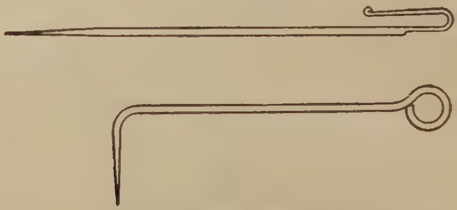


FIG. 9.—Bent and Straight Scribers.

Centre Punch is a small tool shaped similar to Fig. 10, and used for dotting the various centre lines on machine work. It is made from carbon steel, the point being hardened and tempered.

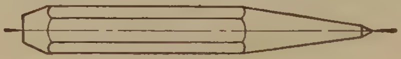


FIG. 10.—Centre Punch.

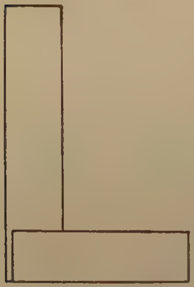


FIG. 11.
Try Square.

Try Square.—The try square is used to test the accuracy of two surfaces at right angles to each other. This tool is shown at Fig. 11. The best form of try square is made from one piece of metal, hardened and ground, to ensure accuracy. The cheaper class of square is made from two or three pieces of steel riveted together, and afterwards filed and scraped to size.

Scribing Block.—The scribing block or surface gauge is made in a variety of forms, and often consists of a steel pillar fitted to a cast-iron base, with various adjustments for altering the height of the scriber point. It is used for marking off centre lines on work parallel to a common base.

In using the surface gauge the scriber should not be allowed to project further than is absolutely necessary, and when moving the block, the scriber should follow the pillar, and not be used at right angles to it. A simple form of this gauge is shown in Fig. 12.

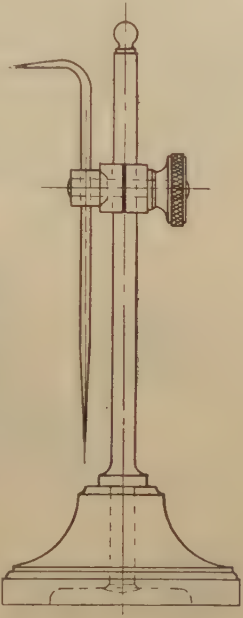


FIG. 12.—Surface Gauge or Scribing Block.

A universal scribing block or surface gauge is illustrated in Fig. 12A. This tool can be used for a variety of purposes, and some of the methods of using the same are shown on page 9.

Micrometer Calipers. — To obtain accurate external measurements the micrometer caliper is used. These instruments are constructed to measure within one ten-thousandth of an inch, or to read hundredths of a millimetre. The screw, as will be seen from Figs. 13 and 15, is quite enclosed, and thus rendered dust proof. The wearing parts are hardened, and provision is made to take up any wear that may take place.

The measuring points are made in various shapes to suit particular classes of work they are to be used upon, and may be very wide to cover the tops of threads, or pointed to measure the depth of a thread.

The principle of this form of micrometer is :—A screw of known pitch, if moved through a nut, will travel the same distance as the pitch ; if turned through a fraction of a revolution, the travel will be equal to a similar fraction of the pitch.

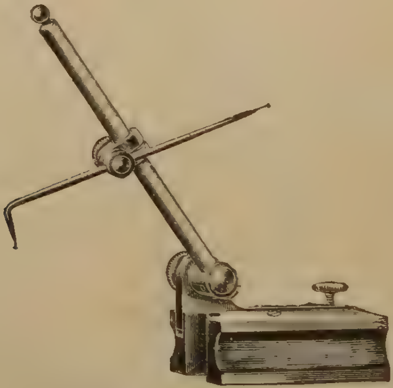


FIG. 12A.—Universal Surface Gauge.

Fig. 13 illustrates a micrometer graduated to thousandths of an inch. The pitch of the screw is forty to one inch. The graduations on the barrel in a line parallel to the axis are forty to one inch, and are figured 0, 1, 2, 3, 4, etc., every fourth division. As these graduations conform to the pitch of the screw, each division equals the longitudinal distance traversed by the screw in one complete revolution, and shows that the micrometer has been opened $\frac{1}{40}$ or $\frac{25}{1000}$ of an inch = .025.

The bevelled edge of the thimble or sleeve is graduated into twenty-five parts, and figured every fifth figure 0, 5, 10,

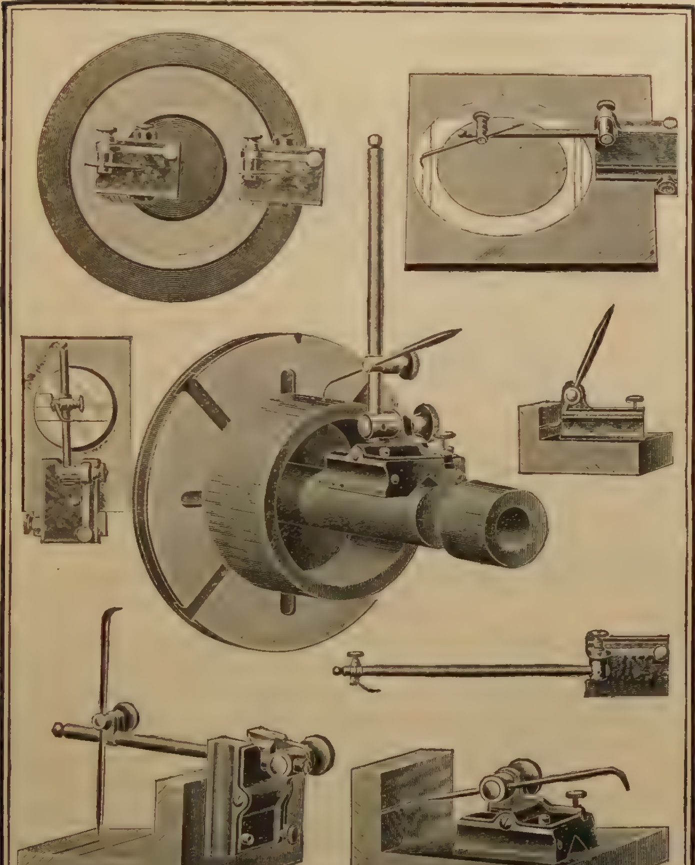


FIG. 12B.—Methods of Using the Universal Scribing Block.

15, 20. Each division, when coincident with the line of graduations on the barrel, indicates that the screw has made

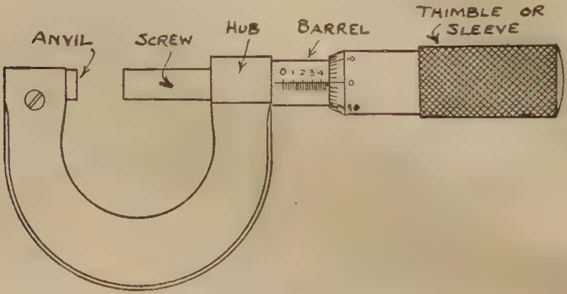


FIG. 13.—Micrometer.

$\frac{1}{25}$ of a revolution, and the opening of the caliper increased $\frac{1}{25}$ of $\frac{25}{1000}$, or $\frac{1}{1000}$ of an inch = .001.

To read the caliper, multiply the number of divisions on the scale of the barrel by 25, and add the number of divisions on the scale of the sleeve from zero to the line coincident with the line of graduations on the hub. The result will be in thousandths of an inch.

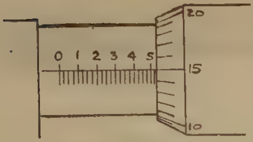


FIG. 14.

Example.—Fig. 14 would be read as follows:—Divisions on barrel, 21 × 25 = 525; divisions on sleeve, 15; then 525 + 15 = 540. Result, 540 thousandths, or .54.

Another method of reading the caliper is to first read the tenths, then the number of fortieth divisions, then the number on the thimble coming opposite the zero line. Taking Fig. 14 it would be thus:—

5 tenths =	.5
1 fortieth =	.025
15 on sleeve =	.015
	.540

A micrometer to read ten-thousandths of an inch is shown in Fig. 15. The readings are obtained by means of a vernier, or series of divisions, on the hub of the caliper as shown. These divisions are ten in number, and occupy the same space as nine divisions on the sleeve, and for convenience in reading are numbered 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 0. Accordingly, when a line on the sleeve coincides with the first line of the vernier, the next two lines on the right differ from each other one-tenth of the length of a division on the sleeve.

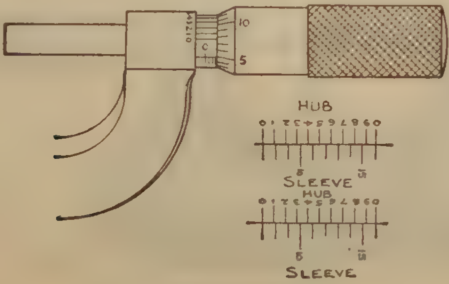


FIG. 15.—Vernier Micrometer.

When the caliper is opened the sleeve is turned to the left, and when a division passes a fixed point on the barrel it shows the caliper has been opened one-thousandth of an inch. Hence when the sleeve is turned so that a line on the sleeve coincides with the second line (end of the first division) of the vernier the sleeve has moved one-tenth of one thousandth, or one ten-thousandth of an inch.

When a line on the sleeve coincides with the third line (end of second division) of the vernier the caliper has been opened two ten-thousandths of an inch. When a line on the sleeve coincides with the fourth (end of third division of the vernier) the reading is three ten-thousandths.

To read a ten-thousandths micrometer, first note the thousandths, fortieths, and tenths, as in an ordinary micrometer, then observe the line on the hub which coincides with a line on the thimble.

If it is the second line marked 1, then add one ten-thousandth; if the third marked 2, add two ten-thousandths, etc.

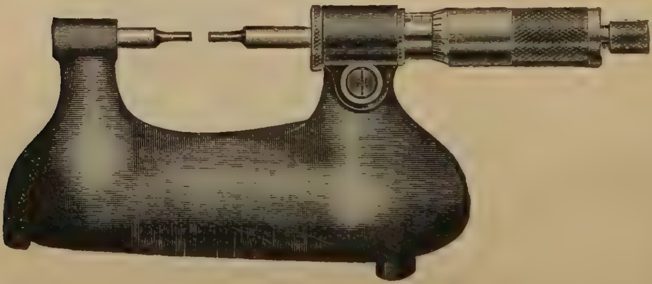


FIG. 15A.—Bench Micrometer.

Micrometers graduated to ten-thousandths should not be used commonly where fine measurements are not required, as a wear which would be of comparatively slight consequence in a caliper which reads only thousandths, is perceptible and important in an instrument of this class.

Fig. 15A shows a bench micrometer. It is made with a stiff heavy base, and can be bolted to the bench. It is very useful for taking fine measurements on work of such a class that can be better inspected and measured at the bench.

The Vernier Caliper.—The vernier is named after Pierre Vernier, who invented the device in the year 1631. A form of vernier caliper is shown in Fig. 16. On the bar of the instrument is a line of graduations divided into inches and numbered 0, 1, 2, etc., each inch being divided into ten parts, each tenth into four, making forty divisions to one inch. On the sliding jaw is a line of divisions, called a vernier, of twenty-five parts. The twenty-five parts on the vernier correspond in extreme length to twenty-four parts on the bar; each division of the vernier is, therefore, $\frac{1}{25}$ of $\frac{1}{40}$, or $\frac{1}{1000}$ of an inch shorter than the corresponding division on the bar.

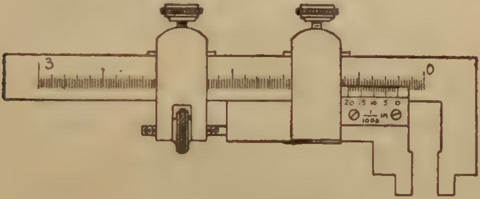


FIG. 16.—Vernier Caliper.

If the vernier is moved until the line marked 0 on the vernier coincides with that marked 0 on the bar, then the next two lines on the right will differ from each other by $\frac{1}{1000}$ of an inch, and the difference will continue to increase $\frac{1}{1000}$ of an inch for each division, until the line 25 on the vernier coincides with a line on the bar.

To read the distance the vernier has been moved, note how many inches, tenths, and parts of tenths the 0 on the vernier is from the 0 on the bar; then the number of divisions on the vernier, commencing with 0 until the line is reached that coincides with a line on the bar.

A simple way of expressing the value is to call the tenths one hundred thousandths (.100); and the fourth of tenths, or fortieths, twenty-five one-thousandths (.025), and then read the thousandths from the vernier.

Example.—Fig. 17 shows the vernier enlarged, and reading by the method shown it would be—number of tenths, 2 × 100 = 200, no fortieths, vernier reading 6. Result, 206 thousandths, or taking the inches, 1.206.

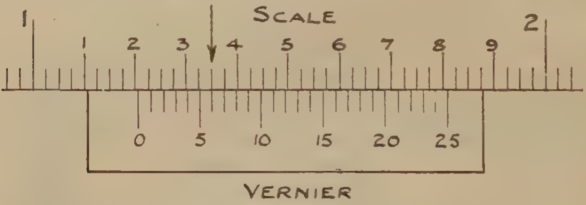


FIG. 17.

Another method is to first read the tenths, then the fortieths, then the number of divisions on the vernier which coincides with a line on the bar. This would be:—

1 inch = - - - - 1.0
2 tenths = - - - - .2
0 fortieths = - - - - .0
vernier = - - - - .006

1.206

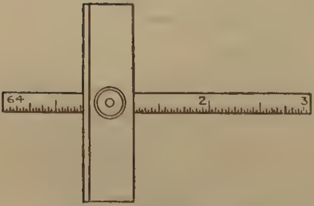


FIG. 18.—Depth Gauge.

The **Depth Gauge** shown in Fig. 18 consists of a narrow steel rule fitting into a foot, being adjusted by hand, and fastened by means of a small milled headed screw. This tool is used to measure the depth of holes and distances from a plane surface to a projection, or work of that character.

Fig. 18A shows a vernier depth gauge. This is a valuable tool where very accurate measurements are necessary. The blade is graduated to read by means of the vernier to thousandths of an inch on one edge, and to 64ths on the other.

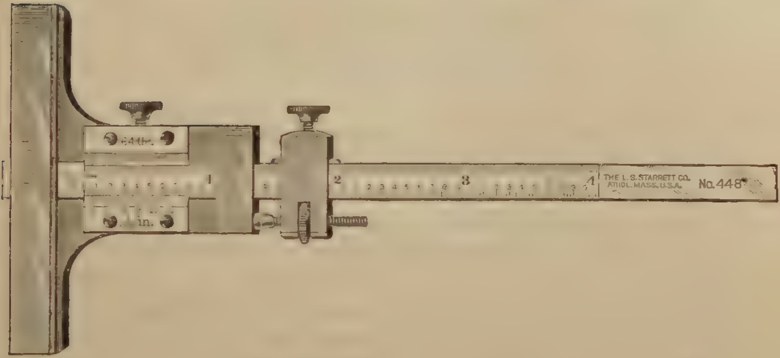


FIG. 18A.—Vernier Depth Gauge.

Cylindrical Gauges.—A pair of cylindrical gauges for internal and external measurements are shown in Fig. 19. By using these gauges work can be turned or bored to a

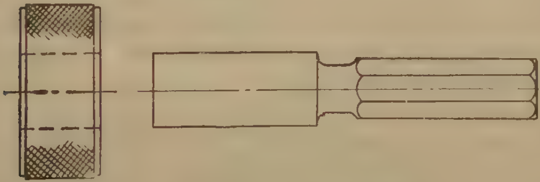


FIG. 19.—Cylindrical Gauges.

particular size, and then tested for accuracy by using the gauges on the work.

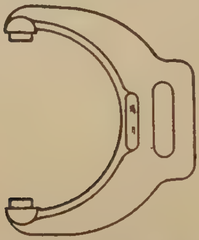


Fig. 20.—Outside Calliper Gauge.

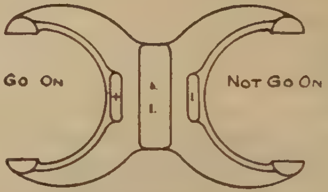


Fig. 21.—External Limit Gauge.

Standard Calliper Gauges are made in various forms, as shown in Figs. 20 to 23. These types of gauges are perhaps the most suitable that can be obtained for general shop work. Fig. 20 illustrates an external gauge; this gauge is sometimes made with adjustable jaws. Fig. 21 shows a gauge by the use of which any error in size can be brought within certain limits. One end of the caliper is made to go on the work, and the other not to go on; therefore, if a shaft is turned so that one side of the gauge goes on, and the other does not, then the work must be within the limit of the two sizes. The same applies to the internal gauge, Fig. 23. One end is equal to the smallest size allowed, the other equal to the largest

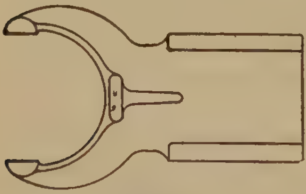


Fig. 22.
Internal and External Gauge.

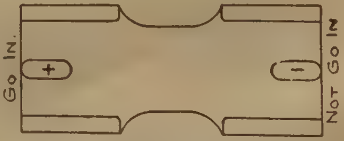


Fig. 23.—Internal Limit Gauge.

size allowable. Another form of fixed caliper gauge is shown, Fig. 22. This, as can be seen, is used for both internal and external gauging.

The Making of a Standard

The determination of correct length is not by any means a simple operation, and the fact that a slight change in temperature alters the dimensions of most metals makes it impossible to guarantee that a measurement is absolutely correct. To show the importance of having a standard measure of length, Messrs Brown & Sharpe decided to make a new standard to replace the one that had been in their use up to the year 1893. Mr O. J. Beale was detailed to do the work. He prepared steel bars about 40 in. long by 1¼ in. square, and after planing them they were allowed to rest for several months. At the end of these bars he inserted two gold plugs, the centres of which were 36 in. apart, and a little beyond these two others were inserted one metre apart. A bar was placed in position on a heavy bed. This was so arranged that a tool holder could be passed over the bar. The tool carrier consisted of a light framework holding the marking tool. One feature of the marking was that the point of the marking tool was curved and had an angle, so that if dropped it made an impression in the form of an ellipse. In graduations ordinarily the line, when highly magnified, is apt to present at its ends an impression less definite than in the centre by reason of the form of the objective. The line made with the tool, as stated, is short, and that portion of the line is read which passes, apparently, through the straight line in the eye-glass of a microscope. In order to make these lines as definite as possible, the point was lapped to a bright surface. After being placed in position the microscope, which could be placed on the front of the tool carrier, was set to compare with the graduation on the standard bar from which the new bar was to be prepared. After such a setting the readings were made by three persons, and by turning the lever the marking tool was dropped, making a very fine line, so fine indeed that, when the authorities in Washington began the examination of the bar, later on, they declared that no line had been made upon these studs.

After making the first line, the carriage was moved along to compare with the other line on the standard, and after the correction had been made by use of the micrometer in the microscope, the marking tool was again dropped, giving the second line, which was intended to mark the limit of one yard all over. The same operation was repeated in the marking of the metre. The whole of this work was done with the greatest care, and while the theoretical portion appears very simple in detail, it required a great deal of time and patience before the last line could be made. The bar was taken to Washington and compared with the standard. In comparing this standard, a process was gone through which was similar to that used in marking it. The bar, properly supported, was placed upon a box that rested upon rollers, and on this same box was placed the Government Standard. The standard was placed in position under the microscope, and after being properly set to the standard the bar to be measured was placed under the microscope and the micrometer screw of the microscope, and the variation was measured. Three comparisons were made by three different persons on each end before determining the reading of the microscope, and after such comparisons and many repetitions of them, the value of the standard was found to be 36.00061 in. for the yard and 1.0000147 m. for the metre.

Allowances for Various Classes of Fits

The Newall system of allowances for various classes of fits is founded on the "hole basis," by which all holes are produced as near standard size as is commercially possible. Classes A and B are commercial limits in two grades.

Limit of Errors for Standard Holes

Nominal Diameters.	Up to $\frac{1}{2}$ in.	$\frac{9}{16}$ to 1 in.	$1\frac{1}{16}$ to 2 in.	$2\frac{1}{16}$ to 3 in.	$3\frac{1}{16}$ to 4 in.	$4\frac{1}{16}$ to 5 in.	$5\frac{1}{16}$ to 6 in.
High limit	+ ·00025	+ ·00050	+ ·00075	+ ·00100	+ ·00100	+ ·00100	+ ·00150
Low ,,	− ·00025	− ·00025	− ·00025	− ·00050	− ·00050	− ·00050	− ·00050
Tolerance	·00050	·00075	·00100	·00150	·00150	·00150	·00200
High limit	+ ·00050	+ ·00075	+ ·00100	+ ·00125	+ ·00150	+ ·00175	+ ·00200
Low ,,	− ·00050	− ·00050	− ·00050	− ·00075	− ·00075	− ·00075	− ·00100
Tolerance	·00100	·00125	·00150	·00200	·00225	·00250	·00300

Two series of limits for holes are given in the above table, because the margins allowed in Class A are smaller than necessary for some classes of work.

Allowances for Driving Fits

Nominal Diameters.	Up to $\frac{1}{2}$ in.	$\frac{9}{16}$ to 1 in.	$1\frac{1}{16}$ to 2 in.	$2\frac{1}{16}$ to 3 in.	$3\frac{1}{16}$ to 4 in.	$4\frac{1}{16}$ to 5 in.	$5\frac{1}{16}$ to 6 in.
High limit	+ ·00050	+ ·00100	+ ·00150	+ ·00250	+ ·00300	+ ·00350	+ ·00400
Low ,,	+ ·00025	+ ·00075	+ ·00100	+ ·00150	+ ·00200	+ ·00250	+ ·00300
Tolerance	·00025	·00025	·00050	·00100	·00100	·00100	·00100

A driving fit is where the parts are to fit tightly together without the slightest movement, and still be able to be driven apart. As an example: The mandrel driven in a piece of work for turning purposes; the mandrel would be turned to within the limits shown above, a little oil would be applied, and it would be driven in with the aid of a lead hammer or a piece of hard wood.

Allowances for Push Fits

Nominal Diameters.	Up to ½ in.	$\frac{9}{16}$ to 1 in.	$1\frac{1}{16}$ to 2 in.	$2\frac{1}{16}$ to 3 in.	$3\frac{1}{16}$ to 4 in.	$4\frac{1}{16}$ to 5 in.	$5\frac{1}{16}$ to 6 in.
High limit	– ·00025	– ·00025	– ·00025	– ·0005	– ·0005	– ·0005	– ·0005
Low ,,	– ·00075	– ·00075	– ·00075	– ·0010	– ·0010	– ·0010	– ·0010
Tolerance	·0005	·0005	·0005	·0005	·0005	·0005	·0005

A push fit is where two parts can be pushed together without the necessity of using force to any great extent.

Allowances for Force Fits

Nominal Diameters.	Up to ½ in.	$\frac{9}{16}$ to 1 in.	$1\frac{1}{16}$ to 2 in.	$2\frac{1}{16}$ to 3 in.	$3\frac{1}{16}$ to 4 in.	$4\frac{1}{16}$ to 5 in.	$5\frac{1}{16}$ to 6 in.
High limit	+ ·00100	+ ·00200	+ ·00400	+ ·00600	+ ·00800	+ ·01000	+ ·01200
Low ,,	+ ·00050	+ ·00150	+ ·00300	+ ·00450	+ ·00600	+ ·00800	+ ·01000
Tolerance	·00050	·00050	·00100	·00150	·00200	·00200	·00200

A force fit is where two parts are forced together to form one piece. This is usually done by means of a screw press, or for large work by means of a hydraulic jack or press.

CHAPTER II

MATERIALS

It is of the utmost importance to the young engineer that he should have a good general knowledge of the properties of materials used in workshop practice. He should also be acquainted with the process of manufacture and the treatment of raw materials previous to their use in the shops.

Steel is a compound of carbon and pure iron; it is often combined with such elements as silicon and manganese, and for special purposes with vanadium, chromium, tungsten, and nickel.

The hard steels contain about 1.2 to 1.6 per cent. of carbon, and the soft or mild steels from 0.15 to 0.4 per cent.

The Properties of Steel.—*Mild Steel*, or steel produced from Bessemer or Siemens open hearth ingot process, has taken the place formerly occupied by wrought iron. It can be bent while cold, it does not harden, and it can be welded. The lower the ultimate strength the higher is its elasticity. Ordinary mild steel bars have an ultimate tensile strength of about 30 tons per square inch, and an elongation of 25 per cent. A steel with slightly more carbon may have a tensile strength of 40 tons per square inch, with about 15 per cent. of elongation.

Cast Steel is a form of highly carbonised steel having from 1.2 to 1.6 per cent. of carbon. It is flexible, tenacious, and has a high degree of elasticity. Its tensile strength is varied to suit the particular work for which it is needed.

Tungsten Steels and other special steels have different properties due to presence of small percentages of other elements than carbon and iron.

Manufacture of Steel

Bessemer Steel.—The Bessemer process consists in converting molten cast iron into pure iron, and by the addition of a known amount of carbon, changing the pure iron into steel.

The converter consists of a pear-shaped vessel lined with firebrick, ganister, or dolomite. The apparatus is mounted on hollow trunnions, through which the air is forced and conveyed through a number of tuyeres inserted at the bottom of the converter.

Before being run into the converter the pig iron is melted, and the inside of the converter made hot by means of a charcoal fire. The metal is poured from a ladle, and air is blown in for about twenty minutes ; this causes a shower of sparks to be emitted. The blast prevents the metal settling in the tuyeres, and after about fifteen minutes it is gradually decreased ; by that time the flames subside, and the sparking is stopped, thus denoting that the conversion of the carbon is complete.

The metal is then in a liquid state, and the converter is rotated to the horizontal, and from 6 to 10 per cent. of Spiegeleisen is added. This is a white pig iron containing a known proportion of carbon and manganese.

The steel is then poured into a ladle, and from the ladle into iron ingot moulds. As soon as the steel has solidified, the mould is lifted away, and the ingot is reheated and run through grooves of a cogging mill, and finally rolled into rails, bars, or the shape required.

Open Hearth or Siemens Steel.—This steel is produced by melting, in large reverberatory furnaces fired with gas, a certain quantity of pig iron, and adding oxide of iron in the form of hematite, the necessary amount of carbon being afterwards added in the form of ferro-manganese. The process being slow, the amount of carbon in the metal can be ascertained by testing a sample piece, which is removed by means of a ladle, quenched, and broken up, and then tested by the chemist. If the test proves satisfactory the metal is run into ingot moulds. The pig iron used for this process must be free from sulphur and phosphorus, as these cannot be removed during the process.

The Siemens-Martin Process is slightly different to the above method of making steel, the difference being that pig iron and scrap steel are used, without the addition of the hematite ore.

Blister Steel is produced by a process known as cementation, and is largely used for converting into other classes of steel. The best selected bars of wrought iron are placed in a furnace and packed tightly with charcoal, the fire is lighted, and in about two days the conversion begins; the temperature is maintained for nine days or more according to the amount of carbon required in the steel, which ranges between 0.6 and 1.6 per cent. The fire can then be drawn or allowed to burn out, and the metal is withdrawn, when it will be found to be covered with blisters. As the outer surface of the metal contains more carbon than the inner, in order to produce a better class of steel the bars are cut into short lengths, treated with a flux of borax and sand, heated to a white heat, and then hammered. According to the number of times this process is gone through it is called *Double or Single Shear Steel.*

Spring Steel is blister steel that has been heated to an orange-red colour, and then hammered and rolled.

Crucible Cast Steel is sometimes made by cutting blister steel into short lengths, and melting it in a crucible of clay or a plumbago pot, and then pouring it into iron moulds.

A more modern method is to melt best Swedish bar iron in crucibles with small quantities of charcoal, afterwards adding oxide of manganese.

Tungsten Steel is a steel containing tungsten, and is made by a similar method to that of crucible cast steel, tungsten being added.

Nickel Steel, Chrome Steel, and **Mushet Steel** are all obtained by slight variations of the crucible cast-steel process.

Nickel Steel.—As illustrating the influence of nickel on steel, an ultimate tenacity of about 40 tons can be obtained from a 3 per cent. nickel steel having a percentage of carbon as low as 0.175, whereas to obtain this strength in ordinary steel, at least 5 per cent. of carbon would be required, which would make the metal so brittle that it would be unreliable.

Vickers' Self-hardening Nickel Chrome Steel combines great hardness, resistance to abrasion, and absence of brittleness, and is used greatly for gear wheels of motor cars. For machining purposes it is necessary to thoroughly anneal at a low heat. To harden, it is simply necessary to bring it to a cherry red, and allow it to cool in the open air.

Wrought Iron is nearly pure iron, and contains less than 0.5 per cent. of impurities. The process of manufacture from pig iron often takes two forms. The first process, called refining, is done in what is known as a refinery. The pig iron is placed in layers with coke upon a bed of lighted fuel, and an air pressure of about 2 lbs. is kept up. The charge is melted in about two hours, and in another hour the air blast has oxidised the impurities in the iron, and a plate of metal is formed ; this is broken up and taken to the reverberatory or puddling furnace. The puddling furnace is made of cast-iron plates lined with firebrick, and the roof is dome-shaped to reflect the heat on the iron.

A charge consists of about 4 cwt., and this amount will take about half an hour to become partly melted, and form a pasty mass. The damper of the furnace is then lowered, and the iron is thoroughly rabbled or stirred in order to bring every part under the oxidising influence of oxide of iron and air. The carbon combining with the oxygen passes off as CO_2.

The puddler then draws the particles of malleable iron, which are floating on the slag, together, in the form of balls called blooms, and these he places on the bridge of the furnace, where they receive the full heat. The balls are then hammered or squeezed by means of a shingling machine, and while still hot they are rolled into bars called puddled bars. The quality of these bars is very inferior, and is only suitable for common girder work, etc. To improve the quality, the bars are cut into short lengths and piled crossways into a faggot, they are reheated, hammered, and rolled, and become what is commercially known as merchant bars. This process of piling, reheating, hammering, and rolling may be repeated several times, its strength by that means being improved, and its quality more uniform.

Good wrought iron should have a silky fibre and a tensile strength of from 25 to 27 tons, an elongation of 25 per cent., and a contraction at fracture of about 50 per cent., and should be capable of being bent double when cold.

Cold Shortness in wrought iron, or brittleness when cold, is caused by the presence of a small amount of phosphorus.

Red Shortness, or brittleness when hot, is produced by the presence of sulphur.

Hammering or drawing wrought iron produces a degree of hardness, but if thoroughly annealed it returns to its original state.

Cast Iron is a material obtained direct from iron ore in the blast furnace. According to the proportions of the charge put into the blast furnace, the cast pig iron obtained differs in appearance and strength.

In the white cast iron the carbon is in chemical combination with the iron, which renders it very hard and brittle. In the grey cast iron the carbon is more in the form of black lead or graphite, and consequently is much softer.

Cast iron generally contains about 5 per cent. of carbon, about half of which is chemically combined, the rest being in the form of graphite.

The following table shows the relation of quality and composition of cast iron :—

	Combined Carbon.	Graphite Carbon.	Silicon.
Greatest softness - - -	0·15	3·1	2·5
„ hardness - - -	...	...	under 0·8
„ general strength - -	0·5	2·8	1·42
„ tensile strength - -	...	...	1·8
„ crushing strength -	over 1·0	over 2·6	about 0·8

The grey cast irons are classed Nos. 1, 2, 3, the white and harder irons Nos. 4, 5, 6, and 7, and are only used for conversion into wrought iron.

The No. 1 iron is low in strength, and is seldom used, most castings being a composition of Nos. 1, 2, and 3.

	Composition of Cast Iron.		
	No. 1.	No. 2.	No. 3.
Iron	90·24	89·31	89·86
Combined carbon	1·02	1·79	2·46
Graphite	2·64	1·11	0·87
Silicon	3·06	2·17	1·12
Sulphur	1·14	1·48	2·52
Phosphorus	0·39	1·17	0·91
Manganese	0·38	1·60	2·72

Remelting cast iron up to a certain number of times greatly increases its strength and density. This is due to the removal of the carbon, and to the metal becoming more like wrought iron in composition.

The following table shows the increase of tensile strength due to longer fusion and remelting :—

	Tensile Strength. Tons per Sq. In.
No. 1	7·5
,, 2, after 2 hours' longer fusion	8·3
,, 3, after 1¾ hours' longer fusion	10·8
,, 4, remelting	11·0
,, 5, after 4 hours' longer fusion	18·5
Maximum of fifth samples	19·6

From the above it follows that the iron product from the blast furnaces is very rarely used alone, but in conjunction with scrap metal, which latter being remelted gives the desired qualities of greater tensile strength.

The Blast Furnace.—The blast furnace is constructed of wrought-iron plates, lined with firebrick or some other refractory material.

The iron ore, which has first been calcined, is fed in at the top combined with lime to act as a flux, and also with coke.

The size of the furnaces varies between about 50 and 100 ft. in height. The air blast is admitted under pressure through tuyeres, being first heated in stoves to a temperature of about 1,000° F.

When the charge is tipped into the top of the furnace it falls upon a hopper or cone, which can be raised or lowered as desired. This prevents the escape of the hot gases into the atmosphere.

The furnace is shaped with the widest part in the middle, and tapered towards the top and bottom; this prevents the molten metal falling in one mass on to the hearth.

As the iron melts, being heavier than the fuel, it sinks on to the hearth of the furnace, where it is tapped and run into ingots called pigs. The slag is run off into tubs about 3 ft. above the tapping hole.

Malleable Castings.—In order to produce a malleable casting the casting is first made in the ordinary manner, and then annealed and partly decarbonised by being brought to a blood-red heat and placed in contact with oxide of iron (hematite), rusty steel turnings, or some other oxidising material.

The period of decarbonisation varies between two and seven days.

Malleable castings can be hammered and bent, but cannot be forged in a manner similar to wrought iron.

Chilled Castings.—If molten cast iron is brought into contact with cold iron the surface becomes hard or chilled. The effect upon molten grey iron is to decarbonise it to a certain depth, causing that part to become white iron. This varies between $\frac{1}{8}$ to $\frac{1}{2}$ inch.

Contraction Allowance of Castings

Most metals expand when heated and contract on cooling, and owing to the hot metal contracting after it has been poured into moulds, it is necessary to make the patterns larger than the casting required, the allowance being expressed as so much per foot. The following table gives the usual allowances, but they are in every way approximate, as only practical tests will give definite allowances :—

	In.		In.
For cast iron in large cylinders - -	$\frac{3}{32}$	In zinc - -	$\frac{5}{16}$
,, ,, ,, small cylinders - -	$\frac{1}{16}$	,, tin - -	$\frac{1}{4}$
,, ,, ,, pipes - - -	$\frac{1}{8}$	,, copper -	$\frac{3}{16}$
,, ,, ,, girders and beams -	$\frac{1}{16}$	,, bismuth -	$\frac{5}{32}$
,, castings in thick brass - -	$\frac{5}{32}$	,, lead -	$\frac{5}{16}$
,, ,, ,, thin brass - - -	$\frac{1}{8}$		

Metals and Alloys

Aluminium is a white metal somewhat resembling silver, of a bluish hue. It is very malleable and ductile. In tenacity it approaches iron, and its melting point is 1,292° F.

Aluminium Bronzes are alloys of copper and aluminium, the copper being in a larger proportion than the aluminium. The value of these alloys consists of their non-corrosive properties and their increased strength.

Copper is found in nearly every country of the world, either as an ore or in a metallic state.

It can be extracted from its ores by either a dry or wet process. The simplest form of dry process consists in reducing the ore, which must consist of pure oxide or carbonate, by heating it with carbon. But as the most abundant ore contains sulphur and iron it is not amenable to this process. A different process is resorted to, and which falls into two parts, one being the separation of pure sulphide of copper from the ore, and the other the reduction and purification of the copper.

Lead is soft, malleable, and ductile, but has very little tenacity. Like all ductile metals it flows under pressure, and at a slightly elevated temperature it can be squeezed into rods or pipes. It melts at about 619° F., and volatilises at a bright red heat. It is also a poor conductor of heat and electricity.

Tin is a white metal with a yellowish tinge. It is low in tenacity, but very malleable at a temperature of 212° F. Its melting point is 440° F., and it is not easily volatilised.

Tin Plates.—For the manufacture of tin plates the best soft charcoal iron is used. After it has been rolled and cut to size, its surface is made chemically clean by immersion for a few minutes in dilute sulphuric acid. The sheets are then heated to a red heat in a reverberatory furnace, withdrawn, allowed to cool, hammered flat, and passed between polished rollers, and then washed in dilute sulphuric acid.

This preparation is needed to free the surface of the iron from the slightest portion of oxide to which the tin would not adhere. In order to tin the plates, they are plunged into a vessel of tallow, from which they are transferred to a bath of tin. From this they are taken after a certain time, allowed to drain, and then dipped again.

Zinc is a bluish-white metal, having a crystalline structure. It is malleable and ductile at a temperature between 200° and 300° F., and melts at 773° F.

Tensile and Shearing Tests

Made by Professor Goodman *at Leeds*

	Ultimate Tensile Stress—Original Section.	Ultimate Tensile Stress at Point of Fracture.	Reduction in Area.	Ultimate Shearing Stress—Original Section.
	Tons per sq. in.	Tons per sq. in.	Percentage.	Tons per sq. in.
Cast iron - - - -	10·9	10·9	Nil.	12·9
Gun metal (soft and ductile)	14·9	19·5	30·7	14·2
,, (hard and brittle)	12·4	12·8	3·0	17·4
Moderately hard steel -	48·0	49·8	7·4	34·0
Mild steel - - -	23·6	29·5	67·5	18·9
Wrought iron (soft) - -	21·7	27·4	49·8	17·4
,, (merchant) -	22·6	24·7	24·6	24·5
Copper (annealed) - -	14·8	23·7	65·0	11·0
,, (hard-drawn) -	17·2	24·1	47·0	23·3
Aluminium - - -	8·8	12·7	45·5	5·6

Definition of Terms in Considering the Properties of Metals

Tenacity.—The property of resistance to the effort of stretching or pulling apart.

Tensile Strength is equivalent to the amount of force applied in a line with its axis to just overcome the cohesion of particles of a test piece and pull it into separate pieces.

Elongation is the amount which the test piece stretches between two fixed points. It is made up of two parts, one due to the general stretch, the other to the contraction at the point of fracture.

Elasticity.—The property of returning to the original shape after a force has been applied and released.

Elastic Limit.—When a metal is subjected to a gradually increasing strain, there is found to be a certain limit within which the stresses are proportional to the strains.

Fusibility.—The property of becoming liquid on the application of heat.

Malleability.—The changing of shape by hammering, pressing, or rolling without causing fracture.

Weldability.—The property possessed by a metal which renders it capable of being joined when in a state of fusion.

Specific Heat.—The relative amount of heat absorbed by metals, compared to the heat absorbed by an equal quantity of water when raised through the same temperature.

Compression is used to indicate the state the particles of a body are in when a force tends to crush the particles together.

Expansion.—The coefficient of expansion is the amount every unit of length expands for every degree of rise in temperature.

Hardness.—The property of the surface of a metal or body to resist penetration by cutting or scratching.

Conducting Power for Heat.—The property possessed in varying degree by metals for transmitting heat along or through them.

Tough.—A material is said to be tough when it can be bent first in one direction, and then in the opposite, without fracturing.

Shearing Strength is equal to the force which, if applied at right angles to the line of axis, would cause the parts to separate.

Ductile.—A material is said to be ductile when it can be drawn and extended by a pulling or tensile force.

Contraction of Area is the amount by which the area at point of fracture has been reduced from its original size, by subjecting it to a pulling force.

Specific Gravity is the ratio of a volume of metal to the weight of an equal volume of water.

METALS

Metal.	Symbol.	Colour.	Derivation of Name.	Discoverer.	Date.	Atom. Weight (New System)	Specific Gravity.	Heat Conductivity. Silver = 100.
Aluminium	Al	Tin-white	Latin : alumen (alum)	Wöhler	1828	27·1	2·56	31·33
Antimony	Sb	Silver-white	Latin : stibium	Valentine	1490	120·43	6·697	4·03
Barium	Ba	Ylwsh.-white	Greek : baros (heavy)	Davy	1808	137·43	3·5-4	..
Bismuth	Bi	White	..	Agricola	1530	208·11	9·759	1·8
Cadmium	Cd	White, blue tinge	Greek : cadmia (calamin)	Stromeyer	1817	112·3	8·65-8·8	20·06
Calcium	Ca	Ylwsh.-white	Latin : calx (lime)	Davy	1808	40	1·82	25·4
Cerium	Ce	Steel-grey	Planet Ceres	Klaproth, Hisinger, and Berzelius	1803	140	5·5	..
Chromium	Cr	Greyish-white	Greek : chroma (colour)	Vanquelin	1797	52·45	6·8-7·3	..
Cobalt	Co	Steel-grey	German : kobold (goblin)	Brandt	1735	58·8	8·52-8·95	17·2
Copper	Cu	Reddish-ylw.	Latin : Cuprum (Cyprian)	..	..	63	8·36-8·95	73·6
Iridium	Ir	Grey	Latin : iris (rainbow)	Tennant	1803	192·5	22·38	..
Iron	Fe	Greyish-white	Latin : ferrum	..	..	56	6·95-8·2	11·9
Lead	Pb	Blue-grey	Latin : plumbum	..	..	206·4	11·4	8·5
Lithium	Li	Silver-white	Greek : lithos (stone)	Arfvesson	1817	7·03	0·578-0·589	..
Magnesium	Mg	Silver-white	Magnesia in Asia Minor	Davy	1808	24·36	1·75	34·3
Manganese	Mn	White-grey	Magnesia in Asia Minor	Gahn	1740	55·02	8	..
Mercury	Hg	White	The Deity and planet Mercury	..	..	200	13·6	5·3
Molybdenum	Mo	Dull silver	Greek : molybdos (lead)	Hjelm	1782	96	8·62	..
Nickel	Ni	White	German : kupfernickel	Cronstedt	1751	58·7	8·3-8·7	..
Palladium	Pd	White	Planet Pallas	Wollaston	1803	106·5	11·4	..
Platinum	Pt	White	Spanish : platæ (silver)	Woods	1741	194·5	21·5	37·9
Potassium	K	Silver-white	Potash	Davy	1807	39·04	0·875	45
Rhodium	Rh	Bluish-white	Greek : rhodon (a rose)	Wollaston	1803	102·7	12·1	..
Silver	Ag	White	..	..	..	107·66	10·4-10·7	100
Sodium	Na	Silver-white	Latin : salsola (soda)	Davy	1807	22·995	0·9735	36·5
Tantalum	Ta	..	..	Eheberg	1802	183	10·8	..
Tellurium	Te	White shining semi-metal	..	..	..	127·49	6·255	..
Thallium	Tl	White	Greek : thallus (green)	Crookes	1861	203·64	11·88	..
Thorium	Th	Greyish-white	Scandinavian god (Thor)	Berzelius	1828	232	11·1-11·23	..
Tin	Sn	Silver-white	Latin : stannum (tin)	..	..	119	7·3	15·2
Tungsten	W	Steel-grey	Swedish : tungsten (heavystone)	J. and F. d'Elhujar	1785	184·4	18·77	..
Uranium	U	Silver-white	The Deity and planet Uranus	Klaproth	1789	240	18·7	..
Vanadium	V	Light grey	Scandinavian : Vanadis, deity	Sefström	1830	51·4	5·5	..
Zinc	Zn	Bluish-white	German : Zink (zinc)	Paracelsus	1541	65·4	6·9-7·15	..

Composition of Alloys

Common brass	- 2 parts copper, 1 part zinc.
Rolled brass	- 32 ,, ,, 10 parts zinc, 1·5 parts tin.
Casting in brass	- 20 ,, ,, 1·25 ,, ,, 2·5 ,, ,,
Propeller brass	- 8 ,, ,, ·5 part ,, 1 part ,,
Gun metal -	- 8 ,, ,, 1 ,, tin.
Muntz metal	- 6 ,, ,, 4 parts zinc.
Babbit metal	- 25 ,, tin, 2 parts antimony, ·5 part copper.
White metal	- 35 ,, copper, 13 parts zinc, 2·2 parts tin.
Aluminium bronze	90 ,, ,, 10 ,, aluminium.

Heat

Coefficient of Expansion for Various Metals

	Linear Expansion.	Surface Expansion.	Cubic Expansion.
Cast iron - - -	·00000617	·00001234	·00001850
Copper - - - -	·00000955	·00001910	·00002864
Brass - - - -	·00001037	·00002074	·00003112
Bar iron - - -	·00000686	·00001372	·00002058
Steel - - - -	·00000599	·00001198	·00001798
Zinc - - - -	·00001634	·00003268	·00004903
Tin - - - -	·00001410	·00002820	·00003229
Mercury - - -	·00003334	·00006668	·00010010

Example.—If a wrought-iron bar is 22 ft. long and is heated from 70° to 300°, find how much it will have lengthened.

Then

$$22 \times (300 - 70) \times .00000686 = .0347116 \text{ ft.} = .41654 \text{ in.}$$

Answer. .416 in.

Approximate Weight of Various Metals

PER CUBIC INCH

	lb.		lb.		lb.
Cast iron -	- 0·26	Steel -	- 0·20	Wrought iron	- 0·28
Platinum -	- 0·78	Bismuth -	- 0·35	Brass -	- 0·31
Lead -	- 0·41	Copper -	- 0·32	Zinc -	- 0·26
Nickel -	- 0·31	Tin - -	- 0·26	Mercury -	- 0·94

Tensile Strength of Various Metals

Material.	Elastic Limit. Tons per square inch.	Maximum Stress. Tons per square inch.	Elongation per cent.
Copper, cast, very pure (average of 4)	...	14·20	...
Copper, rolled - - - -	...	13·3 to 14·2	37 mean
Copper, annealed bar - about	3·90	14·0	40
Gun-metal bar (copper, 64; tin, 8; and zinc, 2 parts) - - -	7·25	13·68	...
Hard rolled bronze - - -	...	26·90	...
Aluminium bronze (copper, 92; tin, ½; aluminium, 7½) - -	9·00	26·40	18
Aluminium, rolled bar - about	7·0	10·0	6
Phosphor bronze - - - -	7·5	15·4	11·4
Delta metal, rolled - - -	22·9	33·3	11·0
Muntz metal, rolled (copper, 3; zinc, 2) - - - - -	11·2	25·46	...
Brass (copper, 2; zinc, 1) - -	...	12·9	...
Tin - - - - about	...	2	...
Lead - - - - about	...	1	...
Zinc - - - - about	...	2·5	...

Ultimate Strength of Metals

Metal.	Tension lb. sq. in.	Compression lb. sq. in.	Shear lb. sq. in.
Aluminium - - -	15,000	12,000	12,000
Brass, common - -	22,000	30,000	36,000
Bronze, manganese -	60,000	120,000	...
Bronze, phosphor - -	58,000	...	...
Copper, cast - - -	24,000	40,000	30,000
Copper, rolled - -	36,000	58,000	...
Iron, cast - - -	15,000	80,000	18,000
Iron, wrought - -	48,000	46,000	40,000
Lead - - - -	2,000	...	...
Steel castings - -	70,000	70,000	60,000
Steel wire - - -	150,000	...	...
Tin - - - -	3,500	6,000	...
Zinc - - - -	5,000	20,000	...

CHAPTER III

VICE WORK

The parallel vice, shown in Fig. 24, is specially designed to eliminate the weakness found in other patterns. It is simple of construction, and can be obtained with jaws varying between 2¼ in. and 5 in. in width.

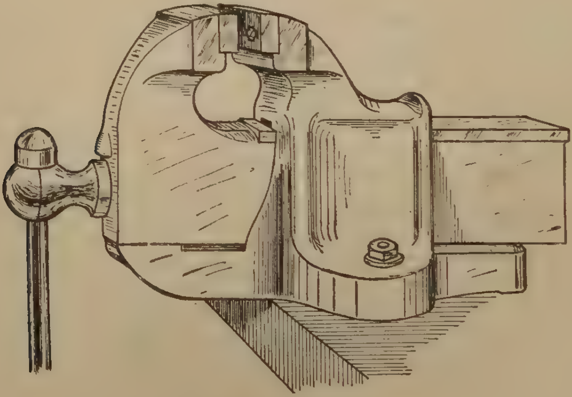


Fig. 24.—Bench Vice.

The hand vice is made in various patterns and sizes, and is used for gripping objects which are too small to be held by hand, and which require the same manipulation as if they were being held by hand. Many of these vices are similar in shape and design to the old-fashioned leg vice.

Vice Clamps.—The jaws of all engineers' vices are faced with hardened steel, and the faces which hold the work are serrated, which make them very liable to cut or bruise the work; therefore, for holding light or delicate work, vice clamps are necessary.

These are made as shown in Figs. 25 and 26, and are cut from sheet iron, brass, or copper. Fig. 25 is a type of clamp frequently cast in lead, and is used when holding work which has to be chipped. It is usual to find in most shops an iron mould prepared, so that worn-out lead clamps can be melted and recast. A useful type of clamp is Fig 26, and it is employed chiefly when keyway cutting or fitting wheels on shafts, and it allows of the shaft being turned round without the necessity of taking the weight by hand each time it is necessary to move it in any way.

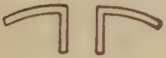


FIG. 25.
Vice Clamp.

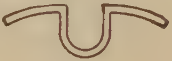


FIG. 26.
Vice Clamp for Round Work.

Filing Blocks. — As it is often impossible to hold very thin work between the jaws of the vice, filing blocks are provided.

They may consist of a flat piece of wood, as shown in Fig. 27, or a board provided with a clamping plate, and which can

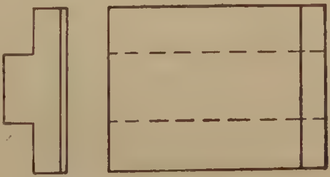


FIG. 27.—Filing Board.

be tightened down by means of two thumb-screws, as shown in Fig. 28. It frequently happens that the fitter, when the necessity of filing thin work arises, obtains a flat piece of wood of suitable size and shape, and to prevent the work from moving drives in a few wire nails.

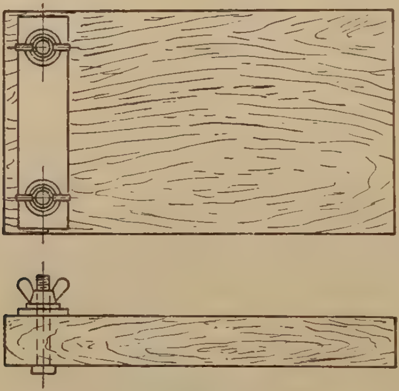


FIG. 28.—Filing Board.

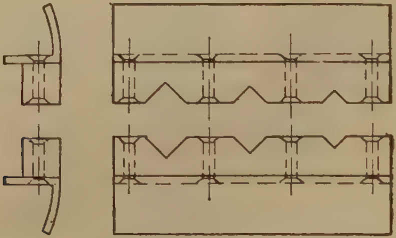


FIG. 29.—Vice Clamp for Special Work.

Holding Pipes or Round Work.—For the purpose of holding round work the device shown in Fig. 29 can be used, the vee-shaped slots being made in various sizes to hold different size work. For holding pipe work, in order to flange over the ends, as would be required with a small hydraulic copper pipe, the tool shown in Fig. 30 can be used, a hole being chosen to grip the pipe which is slightly smaller than the pipe itself.

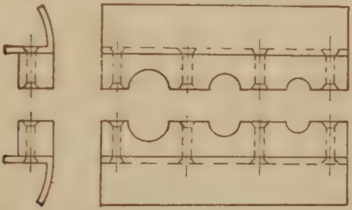


FIG. 30.—Vice Clamp for Flanging Tubes.

Holding Work.—Some considerable practice is required before the student or apprentice can tell exactly how tight a job can be pinched in the vice. It is quite easy to spoil or distort work; therefore, care must be exercised, especially with light or delicate jobs.

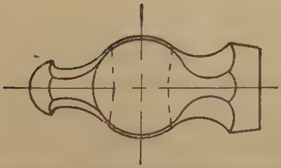


FIG. 31.—Engineers' Hammer.

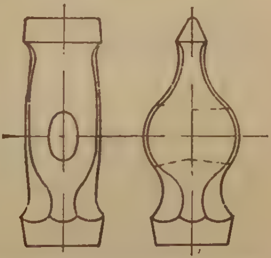


FIG. 32.—Cross Pane Hammer.

Hammers.—The engineers' hammer is shown in Fig. 31. It is generally referred to as a chipping hammer. The heads usually weigh $1\frac{1}{2}$ lbs. A somewhat similar type of hammer is shown in Fig. 32. This is known as a cross pane hammer; when the pane part of the hammer runs in the opposite direction it is called a straight pane hammer. Hammers of this description are chiefly used for riveting and for sheet metal work.

Sledge or flogging hammers weigh from 7 to 14 lbs., and have flat faces. They are used in the fitting shop for such purposes as keying and driving wheels on shafts, and for various heavy jobs which require heavy blows.

Riveting hammers have generally one round pane, the other end of the hammer being flat, and also lengthened to as much as 6 in.; this will allow of riveting in corners, and access to awkward placed rivets.

Lead, Copper, and Hide Hammers.—A lead or copper hammer is a most useful tool, and consists simply of a block of cast metal fitted with a wooden or iron handle. The hide hammer shown in Fig. 33 is made from a piece of iron tube fitted with a handle and partly filled up with leather, the hide projecting a small distance from the ends of the tube.

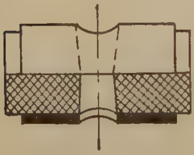


FIG. 33.
Hide Faced Hammer.

Chipping.—Hand chipping is now seldom required in the modern workshop. Before the introduction of machine tools a great amount of work was accomplished by hand, but under modern conditions it is uneconomical and inexpedient to use to any great extent the hand chisel. When it is not possible to use a machine tool, chipping is often carried out by means of the pneumatic chisel, but even in the most up-to-date shops it is sometimes less costly and more expedient to do certain pieces of work by means of hand chipping, and in these special circumstances, or when rapid repairs are required in out of the way places, the ability to use the hammer and chisel in a quick and accurate manner is often of the greatest possible service.

Chisels are made from carbon steel, and vary in length, section, and shape according to the particular work for which they are required. It is usual to forge chisels from bar steel of the same section as that required for the chisel, the ends being heated and hammered to the shape required. The cutting edge is then ground on the emery wheel, the cutting angle being determined by the nature of the metal to be chipped. This varies between 50° and 70°, the less acute being for the harder and tougher metals.

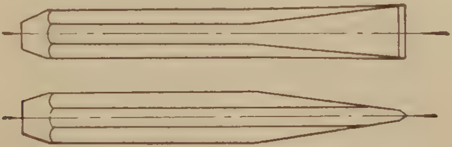


FIG. 34.—Flat Chisel.

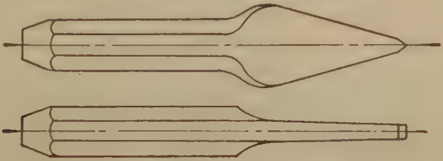


FIG. 35.—Cross-Cut Chisel.

The following may be taken as approximate cutting angles :—

For cast steel	70°	Wrought iron	50°
Cast iron or bronze	60°	Copper and brass	50°

The flat chisel, shown in Fig. 34, is used chiefly for chipping large surfaces or general cutting work.

The cross-cut, shown in Fig. 35, is used for cutting channels on large surfaces previous to using the flat chisel; it is also used for cutting keyways in wheels and shafts.

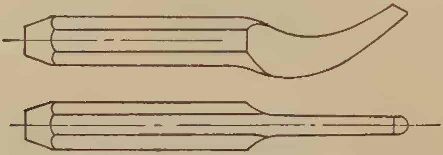


FIG. 36.—Round-Nose Chisel.

The round-nosed chisel, Fig. 36, is useful in cutting oil channels in bearings, brasses, or pulley bushes, or for use when drawing over work that is being drilled, and which may have run out of truth.

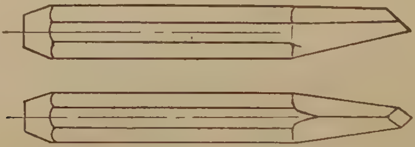


FIG. 37.—Diamond-Point Chisel.

The diamond point, Fig. 37, is chiefly used for chipping through plates, or cutting cast-iron pipes.

The cow-mouth chisel, shown in Fig. 38, is used for enlarging rough holes in plates, or cutting clearances in radial work.

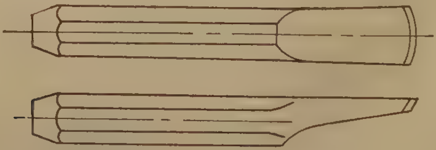


FIG. 38.—Cow-Mouth Chisel.

The side chisel, Fig. 39, is particularly useful in chipping and removing the surplus metal in cotter ways and slots, which may have to be cut by hand after having been drilled.

Using the Chisel.—When chipping, the chisel should be held chiefly with the second and third finger, the index finger being relaxed. The hammer shaft should be grasped at the end, the angle the chisel should be held at, in relation to the work and the weight of the blow, being best determined by actual practice. Brass and cast iron are chipped without the use of a lubricant, but for chipping wrought iron or steel a little oil will improve the cutting action.

In chipping large flat surfaces a number of grooves are first cut across the metal, about $\frac{3}{8}$ of an inch in width, and about 1 in. apart. The depth of each groove being the same, it remains to chip away the surplus metal with a flat chisel, using a straightedge to test for flatness.

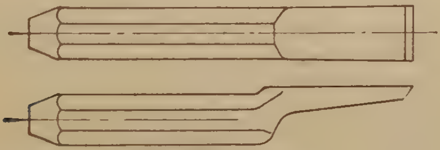


FIG. 39.—Side Chisel.

Note.—Always chip away from the edge of the metal, and not towards it, because there is always a liability to fracture the corners. Keep your chisels sharp; they will cut better and give better results.

Filing.—The file has not fallen into disuse to so great an extent as the chisel, and is still required in special circumstances. It is, however, mainly used to correct work coming from the machines.

Files are graded and classified according to their section cut, and length. They are forged by power or hand from cast steel, the tangs being generally drawn down afterwards by hand. They are then annealed and ground on coarse grindstones to the size and shape required; the teeth are

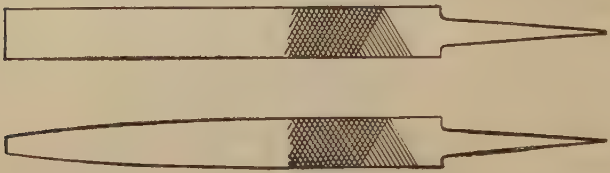


FIG. 40.—Taper and Parallel Files.

then cut either by machine or hand, and the file is then hardened by being heated to a bright red, and plunged into a mixture of salt and water. Files vary between 3 and 16 in. in length, but those in general use are from 4 to 14 in. in

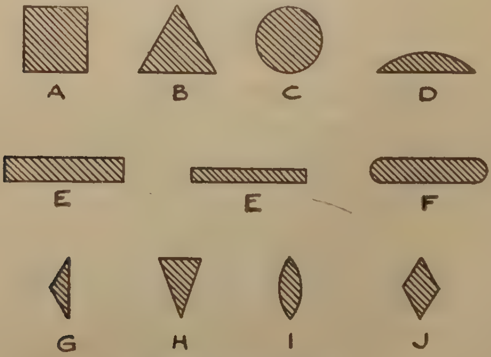


FIG. 41.—Sections of Files.

length, and may be taper or parallel, as in Fig. 40. The various sections of files are shown in Fig. 41: (*a*) being the square file; (*b*) a three-square or saw file; (*c*) round; (*d*) half-round;

(*e*) flat; (*e*) pillar; (*f*) cotter; (*g*) barrette; (*h*) triangular; (*i*) double half-round; (*j*) diamond shape.

Files are graded into some fifteen grades of cuts, namely, rough, middle, bastard, second cut, smooth, dead smooth, all of double and single-cut grade; and also bastard, second cut, and smooth of the rasp-cut grade. The files mostly used are bastard, second cut, and smooth of the double-cut grade.

Filing.—Some skill and practice is required before the file can be used with any degree of accuracy, and the filing of a flat surface is a difficulty only to be overcome by practice. In using the file it is best to stand directly in front of the work, with the left foot advanced about 24 in., holding the end of the file in the palm of the hand, with the handle up against the ball of the right thumb. When cutting, long steady strokes should be taken, putting on weight in the forward stroke, and relaxing on the backward, at the same time keeping the file perfectly horizontal. Any rocking will produce a convex surface.

Cross Filing and **Diagonal Filing** should be used when large surfaces or a large amount of metal has to be removed. Owing to the cuts or grooves formed by the file coming at an angle to one another, a true surface is more likely to be produced.

Draw Filing is a useful method of finishing or polishing metal. The file is grasped in both hands and drawn in one direction along the surface of the work. This brings all the grooves or scratches in one direction, and gives a finished appearance to the work.

When using smooth or dead smooth files on fibrous metals the teeth will be found to clog or pin, and if they are not cleared the file will be found to badly scratch the work. With practical experience of filing this can be avoided to a great extent, but the teeth must be kept cleared by means of a file card or a piece of wood. A little chalk rubbed on the teeth of the file will help to prevent this pinning of the file teeth taking place to any great extent.

New files should always be kept for filing brass or copper

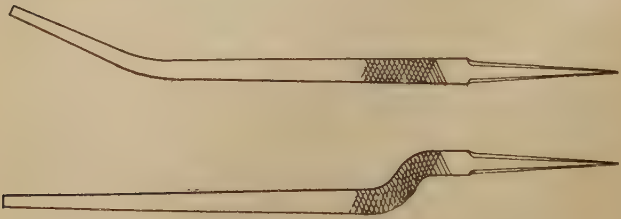


FIG. 42.—Set Files.

alloys, and when the edge has worn off somewhat, they can be taken for use on the harder metals.

Setting Files.—When it is impossible to reach the surface to be filed in the ordinary manner, as would occur in the case of filing a keyway, the file can be heated and set, as shown in Fig. 42. Where a large surface has to be filed,

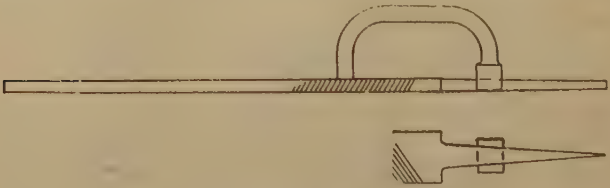


FIG. 43.—Special File Handle.

and it is a considerable distance below the surrounding parts, a file handle, as shown in Fig. 43, can be fitted. For a similar purpose block files are made; these are large in section and short in length, being provided with holes into which a bent handle can be inserted.

Scraping.—As it is not possible, either by machinery or filing, to obtain a perfectly flat surface, it is often necessary to finish work with the aid of the scrape, or, as it is sometimes called, the scraper. It is the only method by which true surfaces can be obtained, and it is applied chiefly to the scraping of cast iron; wrought iron and steel being finished more often by means of smooth files, emery cloth, and emery powder.

Scrapes vary in size and shape according to the particular work for which they are required. It is quite common to make them from old worn-out files. These are heated at one end, hammered out or bent, and then ground smooth. After this they are hardened and tempered, first by bringing the cutting edge to a blood red and dipping into water, and then tempering by holding it close to a red-hot piece of iron until a light straw colour is obtained. The cutting edges of flat scrapers are ground to an angle of 90°, but half-round scrapers should have a more acute angle. After hardening, tempering, and grinding, the scrape should be carefully sharpened on the oilstone.

Scraping Flat Surfaces.—For the purpose of scraping flat surfaces, a surface plate similar to that shown in Fig. 44 is required, also a flat scraper and a little marking. Before commencing scraping, all tool marks should be removed with a smooth file, and the surface filed approximately true.

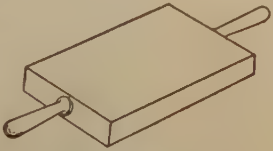


FIG. 44.
Small Surface Plate.

The surface plate is then rubbed over very lightly with a small amount of marking, which is a mixture of black lead or red lead and oil, and the work is then rubbed on the plate. The job can then be held in the vice, and all the transference marks scraped off. This operation is repeated until the binding points are showing over the entire surface.

When scraping a surface, care must be taken to see that no part of the work slides off the surface plate during the time it is being rubbed on for marking purposes. It is therefore necessary to have the surface plate a good deal larger than the work being tested.

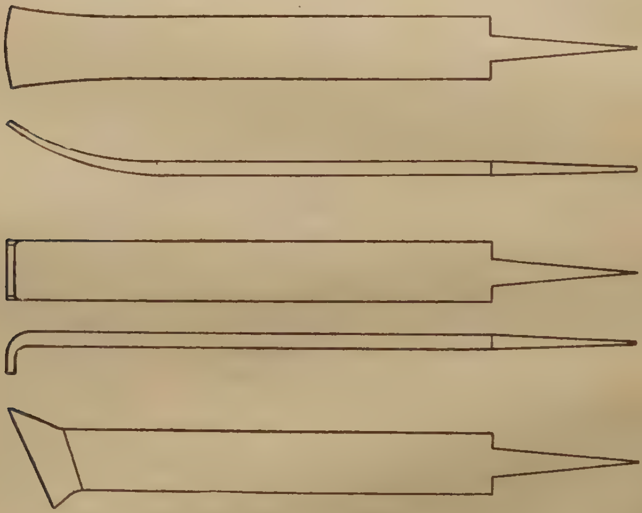


FIG. 45.—Examples of Scrapers.

Scraping Bearings.—Large bearings are generally lined with some kind of anti-friction metal, and are therefore easy to scrape. This is done with flat, half-round, and right-angled scrapers, similar to those shown in Fig. 45. For the purpose of testing the brasses, the journal or bearing on the shaft is rubbed with marking, and the brasses lifted into place and twisted round. Where it is not possible to do this, such as in the case of a large main bearing, skeleton mandrels are provided, and the surfaces of these are marked and used as surface plates. No special difficulty should be met with in scraping, but to accomplish quick, accurate work a fair amount of practice is necessary.

Frosting.—To give a better appearance to work that has been scraped, it is often frosted; this does not in any way increase the accuracy, and is done simply for effect. To produce this, it is first necessary to keep all the scraping in one direction, after which small squares can be scraped with a narrow scraper, either at right angles or diagonally as desired. An oil slip can be made to produce the same effect, and is to be preferred, as it does not remove so much of the metal as the scraper.

Keyway Cutting and Key Fitting.—While in most cases keyways are cut by means of a lathe, miller, or some other form of machine tool, it sometimes occurs that it may be cheaper or quicker to cut them by hand.

Should this be necessary, a cross-cut chisel of the same width as the keyway is used.

It is first necessary to chip or file a flat the same width as the keyway. This is first marked out either by means of a box square or the scribing block.

The keyway is then chipped to nearly the correct depth, and if necessary it can be filed flat on the bottom with a square file, or if it is a feather keyway, it can be filed with a bent file.

Key Fitting.—After the keyway in the shaft and wheel has been cut to the correct depth and width the key can be fitted. The key is first machined all over to nearly the finished size. The key is then tried in by tapping it with a hammer. When it will drive in about half way the keyway should be rubbed with marking; this will show the spots on the key which require filing away.

The process of driving in the key, marking, and removing the hard places that are shown must be repeated until the marks show over the whole of the top and bottom surfaces, and the key is within ½ in. of being right home. The sides of the key should be made to fit, but need not be so accurate as the top and bottom.

Removing the Key.—The correct method of removing a key is shown in Fig. 46; that is by means of a key drift.

When the key is very difficult to remove it can often be overcome by driving the wheel further on the shaft.

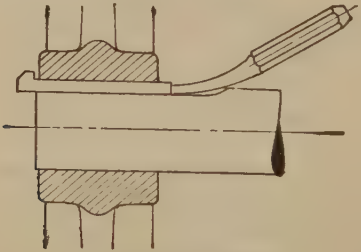


FIG. 46.—Key Drift.

It should be remembered that a little oil rubbed on the key and in the keyway will often prevent the parts seizing together, and save a large amount of time and work.

PROPORTIONS OF KEYS

Diameter of shaft = D. Breadth of key = B.

Thickness of key = T.

$B = \frac{1}{4} D + \frac{1}{8}$ in. $T = \frac{1}{8} D + \frac{1}{8}$ in.

Taper $\frac{1}{8}$ in. per foot, or 1 in 96.

Drifting or Broaching

Broaching or drifting is the process by which holes of various shapes are formed in metal by forcing or driving a drift of the required shape through holes that have been previously drilled. To form square or rectangular holes in work by means of the file takes a considerable amount of time, and a much quicker method is to first drill a hole, then roughly chip it out to size and shape, and afterwards broach it out accurately by means of a drift.

Broaches or drifts are made from carbon steel, formed to the shape required, with the sides left smooth, or cut to form serrated teeth.

Hand Reaming

The reamer is a tool for producing a perfectly smooth hole of standard size, and sometimes consists of a round piece of carbon steel, part of which is machine-cut, with spiral or parallel flutes, in such a manner as to produce cutting edges ; it is then hardened and tempered, and afterwards ground accurately to size. The ends of the cutting edges are made slightly rounding in order to allow the tool to keep in the centre of the hole. A small portion of the ends are slightly tapered, and on some reamers a portion of the end is threaded to produce a self-feeding tool. Hand reamers are provided with a square at one end for turning with a tap wrench.

The Cincinnati Co. of America carried out a series of tests to find the best clearances for various classes of reamers, and the following table shows the most satisfactory results for hand reamers. Table I. is for hand reamers cutting cast iron, and Table II. for cutting steel.

Hand Reamers

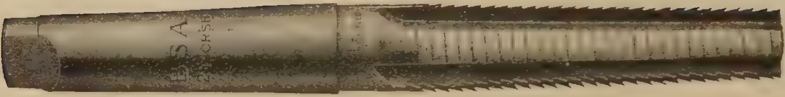


FIG. A.—Roughing Taper Reamer.

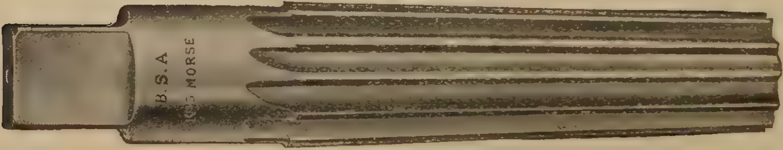


FIG. B.—Finishing Taper Reamer.

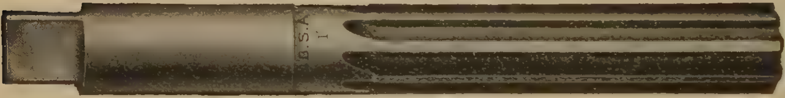


FIG. C.—Parallel Hand Reamer.

FIG. D.—Adjustable Hand Reamer for Blind Holes.

FIG. E.—Adjustable Hand Reamer for Through Holes.
FIG. 46A.

Reamer Clearances

TABLE I.
For Cutting Cast Iron.
Clearance Land ·025 *in. wide.*

Size of Reamer.	For Cutting Clearance.	For Second Clearance.
In.		
$\frac{1}{2}$	·032	·072
$\frac{9}{16}$	·032	·072
$\frac{5}{8}$	·032	·072
$\frac{11}{16}$	·035	·095
$\frac{3}{4}$	·035	·095
$\frac{13}{16}$	·037	·095
$\frac{7}{8}$	·040	·120
$\frac{15}{16}$	·040	·120
1	·040	·120
$1\frac{1}{16}$	·040	·120
$1\frac{1}{8}$	·040	·120
$1\frac{3}{16}$	·042	·122
$1\frac{1}{4}$	·045	·145
$1\frac{5}{16}$	·045	·145
$1\frac{3}{8}$	·045	·145
$1\frac{7}{16}$	·045	·145
$1\frac{1}{2}$	·048	·168
$1\frac{9}{16}$	·050	·170
$1\frac{5}{8}$	·050	·170
$1\frac{11}{16}$	·050	·170
$1\frac{3}{4}$	·052	·192
$1\frac{13}{16}$	·052	·192
$1\frac{7}{8}$	·056	·196
$1\frac{15}{16}$	·056	·196
2	·056	·216

TABLE II.
For Cutting Steel.
Clearance Land ·005 *in. wide.*

Size of Reamer.	For Cutting Clearance.	For Second Clearance.
In.		
$\frac{1}{2}$	·012	·052
$\frac{9}{16}$	·012	·057
$\frac{5}{8}$	·012	·062
$\frac{11}{16}$	·012	·067
$\frac{3}{4}$	·012	·072
$\frac{13}{16}$	·012	·077
$\frac{7}{8}$	·012	·082
$\frac{15}{16}$	·012	·087
1	·012	·092
$1\frac{1}{16}$	·012	·097
$1\frac{1}{8}$	·012	·102
$1\frac{3}{16}$	·012	·106
$1\frac{1}{4}$	·012	·112
$1\frac{5}{16}$	·012	·118
$1\frac{3}{8}$	·012	·122
$1\frac{7}{16}$	·012	·127
$1\frac{1}{2}$	·012	·132
$1\frac{9}{16}$	·012	·137
$1\frac{5}{8}$	·012	·142
$1\frac{11}{16}$	·012	·147
$1\frac{3}{4}$	·012	·152
$1\frac{13}{16}$	·012	·157
$1\frac{7}{8}$	·012	·162
$1\frac{15}{16}$	·012	·167
2	·012	·172

Size of Holes for Reaming

For hand reaming it is usual to leave about four-thousandths of an inch to be removed with the reamer. Reaming holes in two different classes of metal is frequently difficult, and where one metal is hard and the other soft, the tendency is for the hole in the soft metal to finish rather large. Expansion reamers have a number of advantages over the solid reamer. For large work especially the saving in cost is considerable, but unless they are made with great accuracy it is necessary to regrind them after each readjustment.

Reamers are made parallel and tapered both for roughing and finishing. On page 54 various types of reamers are shown. These are manufactured by the Birmingham Small Arms Co., and show at Fig. A a taper reamer for roughing out; Fig. B a taper reamer for finishing; Fig. C the ordinary type of parallel hand reamers; Fig. D an adjustable hand reamer for reamering blind holes; and Fig. E the same type of reamer for through holes. A plentiful supply of oil should be used when reaming wrought iron or steel.

CHAPTER IV

ANNEALING, HARDENING, TEMPERING, CASE-HARDENING

Annealing

IT is hardly necessary to give the various reasons why metals that have been forged, or which have gone through a process of manufacture, should be annealed. All twisting, bending, rolling, welding, or drawing operations invariably set up certain internal or external strains, which in the end cause brittleness. This brittleness is brought about by some portions of the metal being forced into closer grain than others; any surface hardness which may exist is often due to sudden cooling, or the exposure of very hot surfaces to the air. The necessity for annealing becomes much greater when the metal is of odd shape, or when holes of irregular area pass through it.

It is specially desirable that small high carbon steel tools, which require to be hardened after manufacture, should be carefully and thoroughly annealed previous to the finishing cuts in the lathe or machine, the reason for this being that during the hardening and tempering process warping and cracking very often occurs. Shrinking will also be found to take place in some type of tools, and annealing will tend to prevent it to a large extent.

The need for periodical annealing of chains and chain slings used for lifting is generally recognised. The period for which chains should be used depends upon the amount of lifting done by them. Periods should be fixed and adhered to, and should not be longer than twelve months; in the case of crane or crab lifting chains constantly in use, a period of three months would be long enough between each annealing.

The annealing or softening of metal cannot, of course, increase the tensile strength, but it can restore the fibres to their natural and correct position, and also disperse any crystallisation which may have formed during the manufacturing processes, or have been caused by continual straining or working of the metal.

Methods of Annealing

The methods of annealing are fairly numerous, but the object in each method is similar. It must be remembered that when steel of a high temperature is exposed to the atmosphere the surface oxidises very rapidly, and if hardened, is liable to have hard and soft spots, and it is for that reason that all air should be excluded during the annealing process.

The ordinary shop method of annealing work is to bring the piece to a blood-red heat, and leave it in the hot ashes of the forge to cool slowly. This is a rough and ready method, and should never be adopted for intricate work demanding great accuracy. When high grade carbon steel is being softened, it is best to pack it in a box with granulated charcoal, taking care that it is evenly packed, with at least one inch of charcoal surrounding every part of it. The whole should then be placed in an oven, or on a forge, and brought to a cherry red and kept at that temperature about one hour, after which the whole should be allowed to cool, and on no account should the work be taken from the box until quite cold.

For annealing wrought or cast iron a similar method can be adopted, but in place of the granulated charcoal, cast-iron turnings can be used. It is undesirable to use cast-iron turnings when annealing tool steel, as the cast iron has a tendency to decarbonise the surface of the steel, and prevent successful hardening.

A method of softening known as water annealing finds favour with some engineers. It is a much simpler and quicker method than the one just described. The metal is heated to a dull cherry red and tested with a splinter of wood, and when the wood does not char the piece is plunged into water and allowed to cool. Another somewhat similar method is to heat the metal to a cherry red, and then allow the piece to remain in the hot ashes until nearly black, and then plunge into soapsuds.

Water annealing of steel is claimed to give a certain texture to the grain of the metal, but the exact chemical action appears to be doubtful.

Annealing of Copper and Copper Alloys

When copper, or an alloy containing a large percentage of copper, is worked in any way it becomes very brittle, and during any process of manufacture requiring flanging or bending it should be constantly annealed. The softening of copper is a simple operation. The metal is brought to a blood-red temperature in a clean fire or gas flame, and then plunged into cold water. Care must be taken not to overheat the metal, and also to see that the cooling water is quite free from grease.

Hardening

Carbon is known to exist in steel in two forms, one known as Cementite or hardening carbon, the other as Pearlite or softening carbon. All varieties of steel containing more than .5 of carbon become hard and to some extent brittle, if brought to a certain temperature and suddenly quenched in water. This is especially so with high carbon steels. The point of temperature to which the steel must be brought is known as the point of recalescence, or the critical temperature. In the annealed bars as received from the manufacturer the carbon is in the softening stage, and before it can be made hard the pearlite or softening carbon must be changed to hardening carbon or cementite. This change is brought about by bringing the metal to the point of recalescence. It has been found that to harden steel it is necessary to heat it to a cherry red corresponding with a temperature of about 1,450° F. When this temperature is reached the carbon has passed from the softening to the hardening form. If the temperature is allowed to drop below 1,280° F. the change is reversed, or the cementite turned to pearlite, and as some time must elapse between the two periods, it allows of quenching or cooling and thus stopping the change; but the metal must be brought to a temperature below 390° F., and so long as the temperature remains below that no change will take place. If the steel is reheated above 390° F. the character of the carbon immediately commences to change, the steel becoming softer until a temperature of 600° F. is reached, when it again changes its character.

The method of heating steel for hardening purposes may be simply by means of the smith's fire, or for larger work the reverberatory or muffle furnace. With very small work sufficient heat can be obtained by placing the piece on or close to a larger piece of red-hot metal. The gas blow-pipe, worked by means of a foot bellows, is also useful in this direction. Molten metallic liquids are also used, both for heating and cooling, during the process of hardening and tempering.

Tempering

The object of tempering is to obtain a required degree of hardness, and is the imparting of a degree of hardness suitable to the requirements of the tool or part. The more heat imparted to steel during the tempering process, the more the hardness will be reduced.

When a piece of bright steel is exposed to the atmosphere in a hot condition, various colours appear and conduct themselves along the metal as the heat increases. These colours are caused by the formation of thin films of oxide, due to the heat in the metal and the action of the atmosphere, and they correspond with fixed and known temperatures.

Methods of Tempering

Methods of tempering differ greatly, and depend to a large extent upon the nature and size of the work to be tempered.

Two distinct methods are generally adopted, one in which the steel is first fully hardened by bringing it to a temperature of from 1,450° F. to 1,500° F., and suddenly cooling by quenching in water, and afterwards tempering by slowly heating until the required colour or temperature is obtained. The other method is applied chiefly to cutting tools such as chipping chisels, and in this case the hardening and tempering is done in one operation. In the former method the temper can be obtained by several different methods, and for small tools such as taps, drills, reamers, and tools of intricate shape, great care is required, and the best method is to immerse the tool in a molten bath of lead of the required temperature. When only a few articles require tempering, the pieces can be held in the centre of a hot tube until the desired colour is obtained. In the combined method of hardening and tempering, the tool is heated to a cherry red for about 1½ inches, the end is then placed in water to about half this distance, and cooled. The metal being rubbed with a piece of brick or emery cloth until bright will then show the colours approaching the cutting edge, and can be plunged into cold water as desired.

The introduction of special steels for various special purposes, and the addition of such elements as Chromium, Manganese, Vanadium, and Tungsten in varying percentages, has altered all the old methods of tempering. Many of these special steels require special hardening and tempering, and it is advisable to consult the manufacturers as to the correct process.

Mushet high-speed steel is an alloy of steel and tungsten, and is self-hardening. It is mainly used for tools, such as turning and planing tools, twist drills, and milling cutters. For hardening lathe tools the cutting edge is raised to a dazzling white heat, corresponding with a temperature of about 2,700° F., and then immediately placed in a blast of cold air to cool, or plunged into a bath of cold oil.

TABLE OF TEMPERATURES

Approx. Temp. ° F.	Colour.	Approx. Temp. ° F.	Colour.
430	Light straw.	1,080	Red.
450	Straw.	1,300	Dark red.
490	Dark straw.	1,450	Cherry red.
500	Yellow.	1,800	Bright cherry.
530	Brown purple.	2,000	Light orange.
580	Dark blue.	2,400	White.
600	Full blue.	2,550	Brilliant white.
630	Greenish blue.	2,730	Dazzling white.

The following may be taken as the colours and temperatures most used in tempering of steel:—

COLOUR.	TOOL TO BE TEMPERED
Light straw	Scrapers, scribers, lathe tools.
Dark straw	Chisels, drills, drifts, screwing dies.
Brown purple	Hack saws, flat drills, augers, and wood tools.
Dark blue	Springs, screw-drivers, wood saws, cold sets.
Greenish blue	Is too soft for most purposes.

Case-Hardening

The process of case-hardening is applied to many parts of cycles, sewing machines, guns, and small parts of machines where mild steel is being used. It is really a method of converting the skin of mild steel or iron into a form of carbon steel. Owing to the small amount of carbon contained in mild steel it is not possible to harden it, but by means of the case-hardening process carbon can be added to the steel.

Various compounds are used for case-hardening, all of which contain in some form some of the following carbon substances:—bone, charcoal, charred leather, and blood.

The simplest and quickest method of case-hardening is the ferro-cyanide process. For this process potassium ferrocyanide is crushed into powder and placed in an iron tray, the metal is then heated to a cherry red and rolled in the powder, after which the piece is plunged into cold water. Immersion in a bath of molten cyanide will give better results, and will convert the surface into steel to a depth of between $\frac{1}{32}$ and $\frac{1}{16}$ of an inch.

To case-harden castings or articles of unequal proportions, the best material, perhaps, is finely granulated raw bone. This process requires the use of an iron box large enough to allow the metal to be packed with a layer of bone not less than 2 in. thick all round it. The whole is then placed in an oven or furnace and heated to a cherry red, and kept at that temperature for a period varying between two and twenty hours, after which the whole is plunged into water. The time allowed for carbonisation depends upon the size of the article, and the depth of hardening required. Very little advantage is obtained by hardening to a greater depth than one-eighth of an inch.

For case-hardening cutting tools a mixture of equal parts of charcoal and charred leather can be substituted for the bone with advantage.

Colouring Case-Hardened Work

The pieces to be coloured should be first case-hardened with bone and then well polished, after which they should be moved about in a gas flame until the required colour is drawn. They can then be plunged into cold water. All colours between light straw and dark blue can be obtained by this means.

CHAPTER V

PLANING, SHAPING, AND DRILLING

Planing

The planer is constructed to produce flat surfaces of larger area than that obtained by means of the shaping machine.

In most cases the work is secured to a moving table, the tool being held in a tool holder, and fed at right angles to the moving direction of the table.

With edge planers used for truing the edges of large plates the work is fixed, and the tool carriage travels in order to take the cut.

One common form of planer is shown in Fig. 47. It consists of a table with two vee slides fitting in two grooves in the top of the bed, and having two standards supporting a cross bar. The faces of the vertical standards and the cross rail are planed and scraped true. The height of the cross bar can be adjusted by means of a handle working rods and bevel wheels. To the cross bar is fitted a saddle carrying a slide and tool holder, and the saddle can be moved in either direction by hand or automatically through the medium of a square-threaded screw. The tool can be fed up or down by hand, or automatically, and the feed can be altered while the machine is running by reducing the travel of the friction gear.

The table is moved by means of a rack and pinion driven by two pulleys of different diameters, one of which gives a

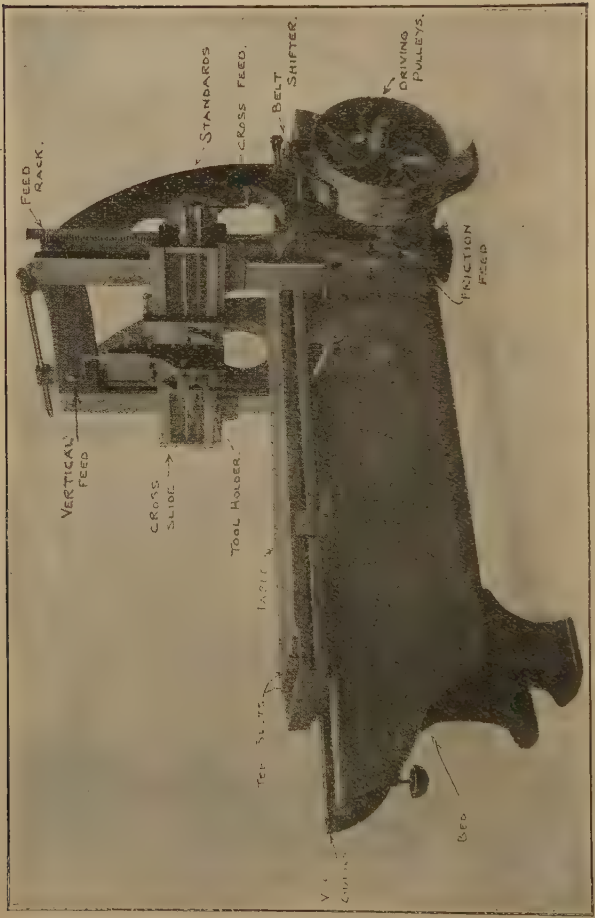


FIG. 47.—Planing Machine.

quick return stroke. The length of stroke is regulated by means of adjustable tappets bolted to the tee-shaped slots in

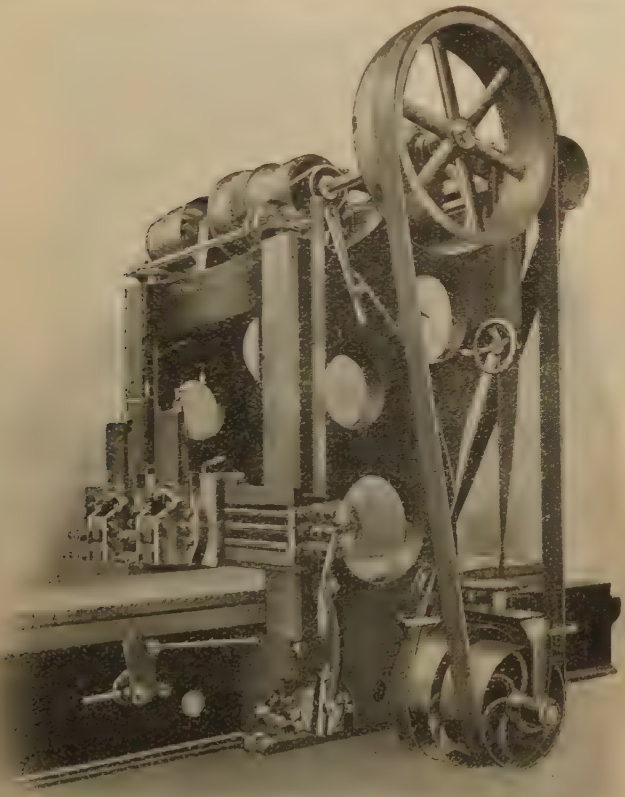


FIG. 48.—High-Speed Planing Machine.

the side of the table, and which strike a lever operating the belt shifting apparatus.

High-Speed Planing Machines.—Fig. 48 illustrates a modern type of high-speed planing machine. This is capable of giving best results with high-speed tools, and has many important and valuable features. The bed is of great depth, well braced with cross girths of box section. The vees are fitted with an automatic oiling arrangement, which will keep them well lubricated. The table is very deep and well ribbed underneath, the tee slots being cut from the solid. The housings are of box section, securely bolted to the bed, and tied together by a deep cross girth. The heads are graduated for swivelling, and have automatic feeds in all directions. For direct driving a motor of constant speed can be used; this is carried on the top of the machine and always runs in one direction. A variable speed drive, self-contained on the machine or as shown in Fig.

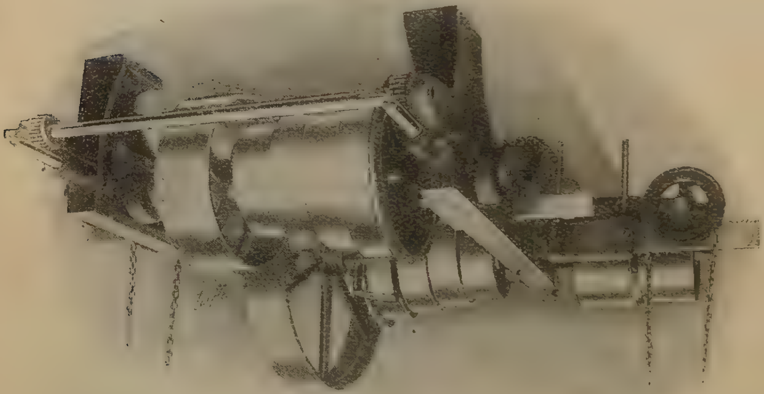


Fig. 48A.—Independent Variable Speed Countershaft.

48A, allows of the following speeds: on sizes up to and including 48″, the cutting speeds are 30′, 40′, 50′, and 60′ per minute, with a return speed varying from 140′ to 90′ per minute, according to the size of the machine. On machines above 48″ the cutting speeds are 30′, 40′ and 50′ per minute, with a constant return speed of 65′ per minute. The drive is by belt, thus doing away with any vibration that might be caused by badly running gears.

Holding Work.—The method adopted for holding work on the planer depends upon the size and form of the job to be planed.

Small work is frequently held in one or more vices as convenient. If the work is large and heavy, it can be secured by means of bolts and plates directly to the table, tee-shaped slots and holes being provided for this purpose.

For holding and fixing various classes of work, angle plates, parallel packing, levelling wedges, hardwood blocks, stopping plates, and other special devices are required to obtain a correct setting of the work.

It is most important that all work should be clamped down in such a manner as to prevent any slipping or springing of the job, the position of the plates or clamps being determined so as not to interfere with the free cutting action of the tool.

Setting Out Work.—The lining up or setting out of work on the planer is generally accomplished by means of the scribing block, spirit level, and try square. The centres can be obtained quite easily from the bed of the machine.

Cutting Speeds and Feeds. — The question of cutting speeds and feeds is practically the same as with the lathe.

The majority of planers are not provided with changeable speed gears, but have usually a fixed speed of about 24 ft per minute. This speed is a very suitable speed for cutting cast iron, but is very much too slow for brass or softer metals.

The speed of belts is, as a rule, not less than 1,000 ft. per minute, the average being about 1,500 ft. per minute for cutting, and about 3,000 ft. for the return stroke.

The feed being adjustable, it can be altered to suit the character of the metal to be cut, and will depend on whether a roughing or finishing cut is being taken. For roughing work it is usual to take as heavy a cut as the tool will stand, using a fine feed. For finishing a light cut or scrape is taken and a coarse feed is used.

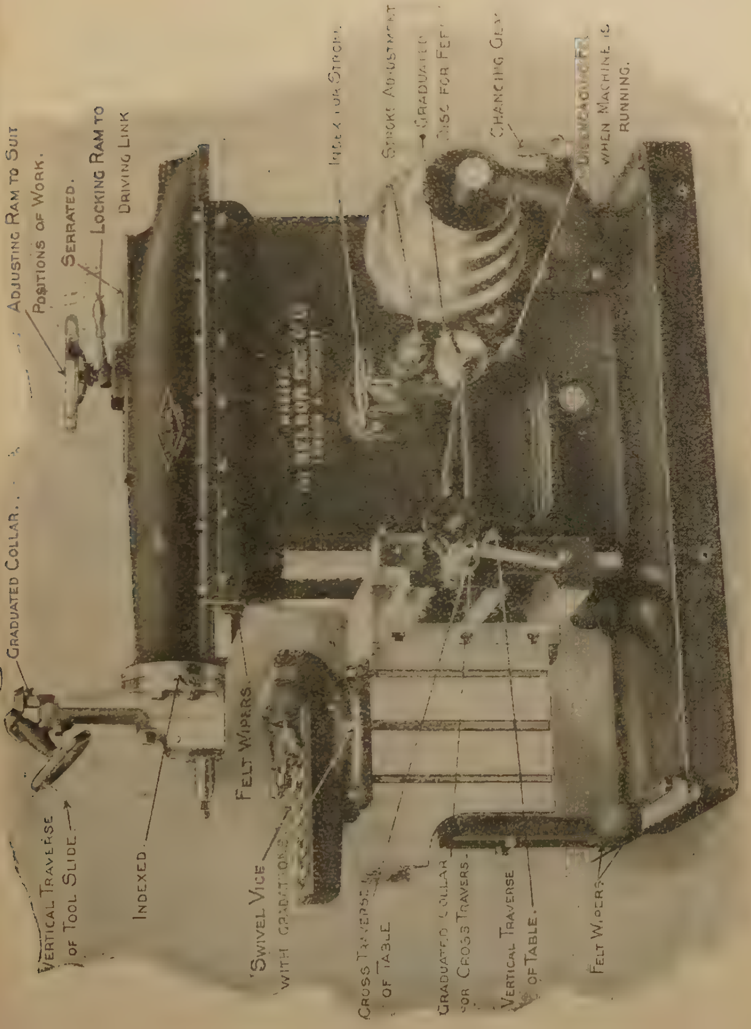
Planer Tools.—The shape and form of planer tools are practically the same as lathe tools, but owing to the absence of any convenient method of altering the cutting angle, it is necessary to have them ground to the correct angle before using. The clearance should be as small as possible, and for roughing work it is not usual to have a cranked tool, but one in which the end is simply set forward and ground to shape.

In many up-to-date shops tool holders made from mild steel are used, the cut being taken by means of small high-grade steel tools, correctly shaped and held at the end of the tool holder. This effects a great saving in tool steel.

Shaping

The shaper is designed to produce work similar to the planer, but on a smaller scale. It differs from most planers inasmuch that the tool moves to give the cut. In some shaping operations the work is made to revolve, and in others the tool is fixed in a ram to give the cut, and the work moves to give the feed.

A modern type of shaper is illustrated in Fig. 49. This machine has many interesting features. The main driving



Adjusting Ram to Suit Positions of Work.
Serrated.
Locking Ram to Driving Link
Indicator for Stroke.
Stroke Adjustment
Graduated Disc for Feed
Changing Gear
Disengaging Feed when Machine is Running.
Graduated Collar.
Vertical Traverse of Tool Slide
Indexed.
Felt Wipers.
Swivel Vice with Graduations
Cross Traverse of Table
Graduated Collar for Cross Traverse.
Vertical Traverse of Table.
Felt Wipers.

Fig. 49.—25-in. Stroke Shaping Machine.

link or rocker arm is connected to a ram by a short link which gives a draw stroke, and ensures a smooth cutting action. The stroke can be altered to any position by a crank handle when the machine is running or stationary. The handle controls a pointer which registers the exact length of stroke. The table is vertically adjusted by hand on the main frame. The cross feed is so arranged that the whole of the feed mechanism can, by depressing a hand lever, be thrown out of action when the machine is running at any speed. The feed can then be altered or reversed with safety without disturbing the driving mechanism. The cross slide is fitted with a micrometer index which can be used for fine adjustments.

Fixing Work.—A great number of shaper jobs can be secured in the vice, which may be swivelled to any position desired. The vice is bolted to the table and fed sideways in either direction, automatically or by hand. When feeding automatically the feeding arrangement works during the return stroke of the ram, the table moving a distance equal to the width of the cut.

Large work can be secured to the top or side of the table by means of bolts and plates, holes and slots being provided for that purpose.

Tools.—The tools used in the shaper are practically the same as in the planer, and often consist of some form of steel tool holder into which tools of various shapes can be clamped.

Circular Work.—Most shaping machines are provided with an attachment for shaping circular work. This arrangement is shown in Fig. 50, and is useful for a large variety of work, such as shaping shafts with solid keys where turning is impossible, or for cutting squares, hexagons, octagons, or circular work. The small sizes are placed direct on the table, and the larger on front of the table slide after the table has been removed, both being arranged to be coupled to the existing feed mechanism to give self-acting horizontal and vertical feed to the work. It is also possible to fit a dividing plate to this gear, and thus do an endless variety of work without the special marking out of the work.

Cutting Keyways.—An extremely simple and effective

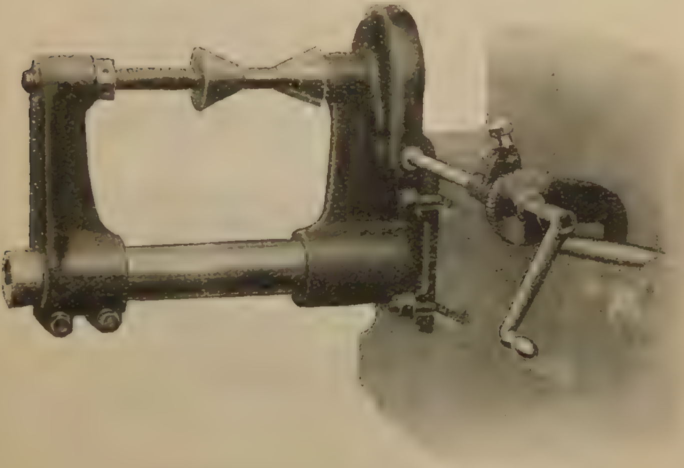


Fig. 50.—Shaping Attachment for Circular Work.

apparatus, which will be appreciated by all practical workmen, is shown in Fig. 51. The usual tool box is removed from the ram head, and replaced by a T-slotted plate to which the work can be bolted. The tool is carried on a special bracket mounted on the table of the machine, this arrangement having the double advantage of being far more rigid than the ordinary type of slender overhanging tool, and also keeping the work in full view of the operator. The ordinary feed is available for this operation.

For special classes of work a circular face plate instead of the slotted plate can be used, or a back plate for carrying a shop chuck.

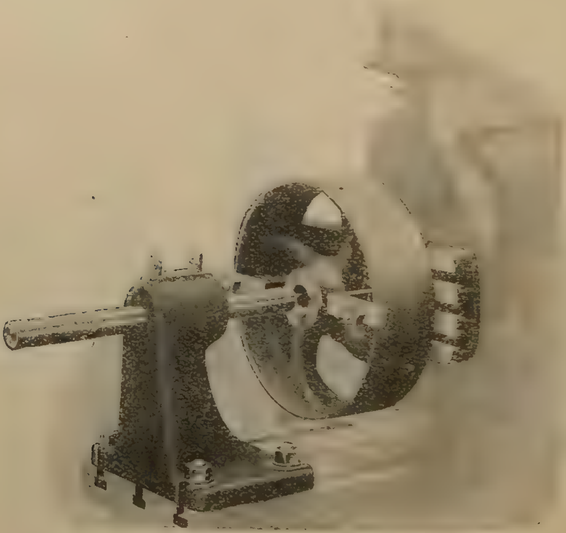


FIG. 51.—Shaping Attachment for Cutting Keyways.

Speed Chart

Speed Chart.—It is usual to attach a speed chart to this type of machine, showing the correct position of the belt and gear shifting handle for various strokes at any desired speed. It does not state the revolutions or number of strokes per minute as, for

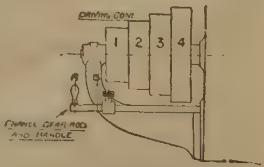


FIG. 51A.

practical purposes, this is quite unnecessary. All the operator has to do is to select the amount of stroke and cutting speed and find from the table which step of the cone and gear to use. This table is also of great value to the foreman or overlooker, as he can see at a glance if the machine is being run at its proper speed.

25-IN. STROKE SHAPING MACHINE

Length of Stroke in Inches	CUTTING SPEED IN FEET PER MINUTE.							
	Gear Change Handle at A.				Gear Change Handle at B.			
	No. of Speed on Cone.				No of Speed on Cone.			
	1	2	3	4	1	2	3	4
3	40	28	18	12	...	...	...	...
6	74	50	35	23	14	10	...	...
9	110	74	50	34	22	14	10	...
12	...	95	67	44	29	19	14	...
15	...	117	77	54	34	23	15	11
18	...	...	93	63	43	28	18	13
21	...	...	109	73	46	32	21	14
25	...	...	130	85	55	37	27	17

Speed of countershaft, 280 revolutions per minute.

Drilling

Drilling Machines are constructed in enormous variety of forms. They may be divided into vertical and horizontal drills, radial and fixed spindle drills, multiple and sensitive drills.

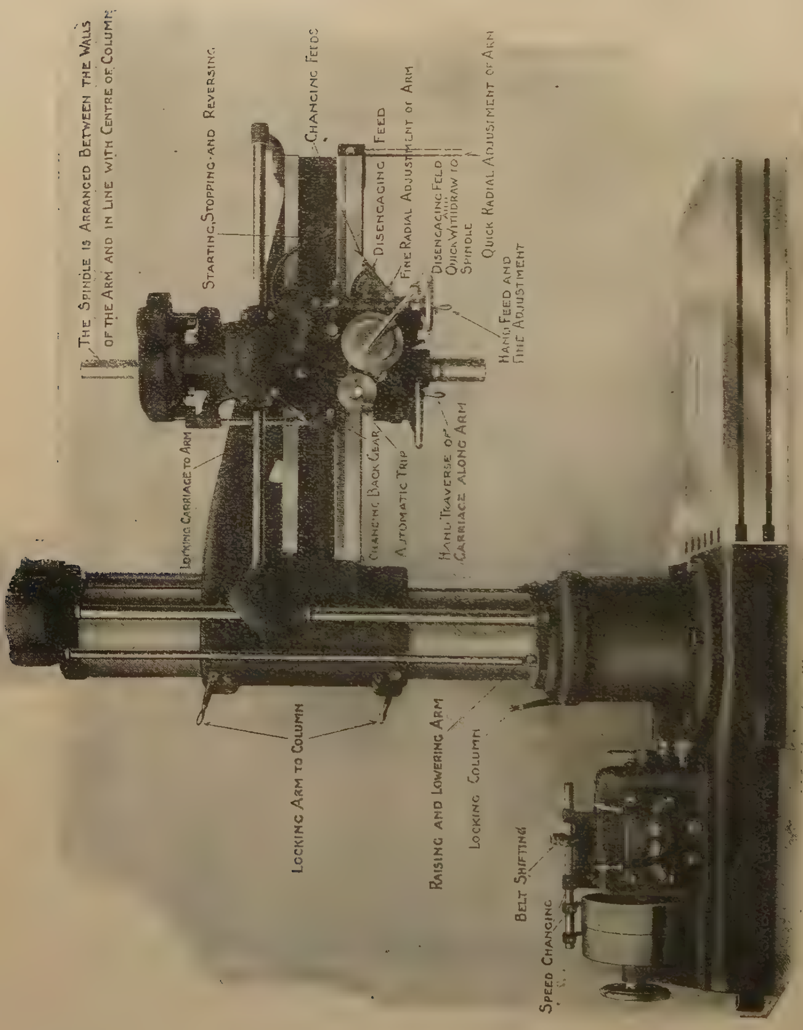

THE SPINDLE IS ARRANGED BETWEEN THE WALLS OF THE ARM AND IN LINE WITH CENTRE OF COLUMN
STARTING, STOPPING AND REVERSING
CHANGING FEEDS
DISENGAGING FEED
FINE RADIAL ADJUSTMENT OF ARM
DISENGAGING FEED AND QUICK WITHDRAW OF SPINDLE
QUICK RADIAL ADJUSTMENT OF ARM
HAND FEED AND FINE ADJUSTMENT
HAND TRAVERSE OF CARRIAGE ALONG ARM
AUTOMATIC TRIP
CHANGING BACK GEAR
LOCKING CARRIAGE TO ARM
LOCKING ARM TO COLUMN
RAISING AND LOWERING ARM
LOCKING COLUMN
BELT SHIFTING
SPEED CHANGING

FIG. 52.—High-Speed Radial Drilling Machine.

The chief features of a good drilling machine are: strength and rigidity of the machine, a good fitting spindle, and, if of the radial type, a strong swivelling arm free from spring.

In the **Vertical Type** of drilling machine a movable table is provided, in order to bring the work correctly under the drill point. The base of the machine is often planed and slotted in order that large or heavy work may be bolted to it.

The **Horizontal Drill** is needed chiefly for drilling work of such a length that it cannot be done advantageously in the vertical drill. These machines have a movable drilling head, and are generally constructed to do such operations as drilling, boring, tapping, and reaming.

A Radial Drilling Machine is shown in Fig. 52, and the various movements are clearly shown. The arm can be swivelled to drill on any portion of the table, and the head can be set over to whatever angle is desired. The spindle can be reversed, started, and stopped by means of one lever, this being of particular use for tapping purposes, both for right and left hand threads.

Multiple or Gang Drills have two or more drilling spindles in the same alignment, or in certain fixed positions. They are generally driven from one common shaft, the spindles being arranged to be run at various speeds and feeds as desired. Fig. 53 illustrates a modern type of multiple drill.

The **Sensitive Drills** are made with one or more spindles which are very sensitive, and should run perfectly true. The feed is given to the drill by means of a lever, and the spindles are generally counterbalanced by means of a weight inside the vertical column.

Drills.—We find several forms of drills in use at the present time, and many great improvements have been made within the last few years. The common or flat drill may be said to have entirely disappeared, and its place taken by

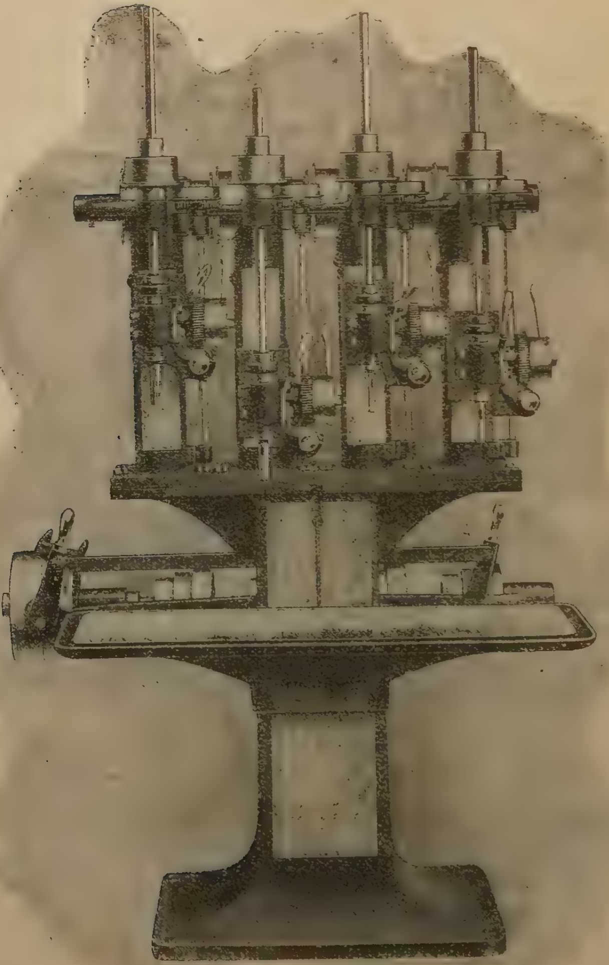


FIG. 53.—Multiple Drilling Machine.

the twisted or twist drill. Fig. 54 shows a high-power twisted drill. The main feature, as will be seen, is the continuous twist from end to end. The increased twist shown in the shank provides sufficient surface, so that the shank is made to fit the regular Morse or other sockets now universally used, thus doing away with anything in the nature of special means of holding and driving the drills. In most cases the drills are provided with one size larger shank than the ordinary carbon steel twist drill, thus giving greater strength to the shank and tang, and making it practically impossible to break the tang under the most severe conditions. These drills are twisted from flat steel under conditions that ensure the greatest possible efficiency.

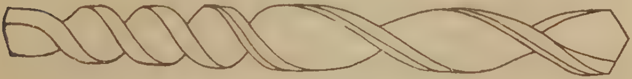


Fig. 54.—High-Speed Drill.

The ordinary high-speed steel twist drill is shown in Fig. 55. These are made with parallel or taper shanks in sizes from $\frac{1}{32}$ in. to 4 in. in diameter. They are invariably made in the milling machine. The fluting is done by means of a special cutter, and the clearance or backing off of the surface is done with an end mill. The flutes are made less in depth as they near the shank, and thus give greater strength. To obtain this difference in depth the dividing head is raised or lowered sufficiently to give the necessary

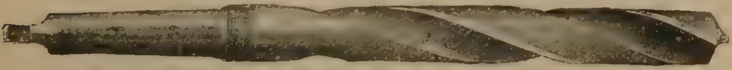


Fig. 55.—Carbon Twist Drill.

variation, which is dependent upon the size of the drill. Fig. 56 shows a four-fluted chucking drill.

Drilling. — The location of holes for drilling is frequently done by means of jigs. These are hardened plates, clamped to the work, and through which the drill can pass.

In **preparing work** for drilling it is usual to first chalk the surface, and then locate the centre by means of the scribing block, dividers, or some other tool. The centre is then punched, and from that mark a circle is scribed by means of the dividers the same size as the hole to be drilled, and if over $\frac{5}{8}$ of an inch in diameter a smaller circle is also scribed. These circles are lightly dotted with the centre punch, and the work is then set up in the machine. Should the drill run out slightly, the smaller circle will show how much, and it may be necessary to draw it over by means of a groove cut with a bent round-nosed chisel on the side required.

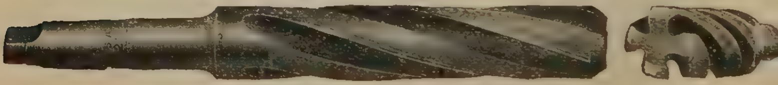


FIG. 56.—Four-fluted Chucking Drill.

When **drilling large holes** it is the best practice to first drill a small guiding hole. This provides an accurate centre for the larger drill to follow, and will often prevent an untrue hole being made. When drilling cast iron or metal likely to be spongy care must be taken to see that the small drill has gone in quite square.

Cored holes are most unsuitable for drilling, which, besides producing an unsatisfactory job, invariably spoil the drills.

When a cored hole must be drilled, a plate should be clamped above the hole to act as a guide for the drill, and the speed and feed greatly reduced. A new drill should on no account be used for this purpose.

Large holes are frequently cut in sheet metal by means of a cutter and bar, as shown in Fig. 57. A hole is first drilled the same size as the end of the bar, and the cutter is adjusted to diameter by means of a cotter.

Arboring holes is done by means of a similar type of bar fitted with a flat cutter, which can be adjusted to take various size cuts, and also to arbor the top or underneath side of a hole.

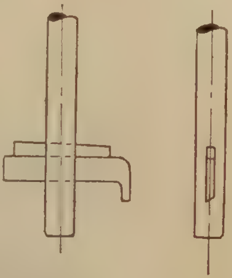


FIG. 57.
Drilling Cutter.

Grinding Drills.—The grinding of the cutting edges of twist drills is of great importance. The cutting edge should have the correct angle, and be uniform with the longitudinal axis of the drill, both being exactly equal, and the lips should be backed off or cleared. If the clearance is insufficient or imperfect it will not cut correctly, and when force is applied it resists the power of the machine and is crushed or split. Drills correctly made and ground have their cutting edges straight when at an angle of 59°.

Grinding to a less angle is likely to produce an irregular hole. The cutting edges should be of exactly equal length; any inequality doubles itself in the work. As the drill is shortened through wear and use, the centre gets thicker and will work hard in drilling. To overcome this the centre should be thinned, and care must be taken to remove an equal amount from each side, and so keep the point central.

In most modern workshops twist drills are ground by means of special drill grinders, similar to that illustrated in Fig. 58. The details of this tool can be clearly seen, and it provides an efficient method of accurately and quickly grinding drills.

Speeds and Feeds. No hard and fast rules can be laid down for speeds and feeds, so much depending upon the nature of the metal, and as this varies to such a great extent it is impossible to give anything except approximate figures.

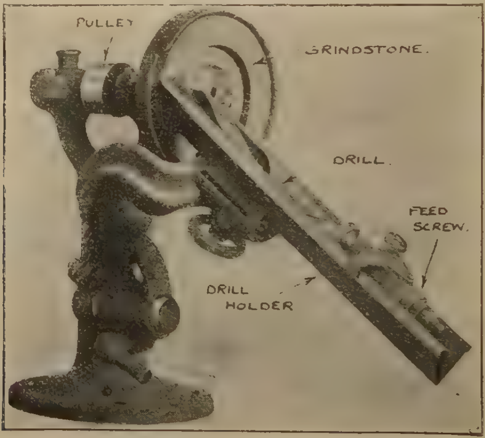


FIG. 58.—Twist-Drill Grinder.

The following may be taken as general shop practice with ordinary carbon steel, but with high-speed steel, speeds greatly in excess of these can be used.

SPEED OF DRILLS

The following table shows the revolutions per minute for drills from $\frac{1}{16}$ to 2 in. diameter, as usually applied:—

Diam. of Drills.	Speed for Steel.	Speed for Iron.	Speed for Brass.	Diam. of Drills.	Speed for Steel.	Speed for Iron.	Speed for Brass.
In.	Revs.	Revs.	Revs.	In.	Revs.	Revs.	Revs.
$\frac{1}{16}$	940	1,280	1,560	$1\frac{1}{16}$	54	75	95
$\frac{1}{8}$	460	660	785	$1\frac{1}{8}$	52	70	90
$\frac{3}{16}$	310	420	540	$1\frac{3}{16}$	49	66	85
$\frac{1}{4}$	230	320	400	$1\frac{1}{4}$	46	62	80
$\frac{5}{16}$	190	260	320	$1\frac{5}{16}$	44	60	75
$\frac{3}{8}$	150	220	260	$1\frac{3}{8}$	42	58	72
$\frac{7}{16}$	130	185	230	$1\frac{7}{16}$	40	56	69
$\frac{1}{2}$	115	160	200	$1\frac{1}{2}$	39	54	66
$\frac{9}{16}$	100	140	180	$1\frac{9}{16}$	37	51	63
$\frac{5}{8}$	95	130	160	$1\frac{5}{8}$	36	49	60
$\frac{11}{16}$	85	115	145	$1\frac{11}{16}$	34	47	58
$\frac{3}{4}$	75	105	130	$1\frac{3}{4}$	33	45	56
$\frac{13}{16}$	70	100	120	$1\frac{13}{16}$	32	43	54
$\frac{7}{8}$	65	90	115	$1\frac{7}{8}$	31	41	52
$\frac{15}{16}$	62	85	110	$1\frac{15}{16}$	30	40	51
1	58	80	100	2	29	39	49

One inch to be drilled in soft cast iron will usually require for $\frac{1}{4}$-in. drill, 125 revolutions; for $\frac{1}{2}$-in. drill, 120 revolutions; for $\frac{3}{4}$-in. drill, 100 revolutions; for 1-in. drill, 95 revolutions.

HIGH-SPEED DRILLING

The speeds shown below are taken from a series of tests made at the works of Messrs Alfred Herbert, Coventry, using high-speed twist drills on patent ball-bearing drilling machines. The cast iron was the same mixture as used for lathe beds, the hardness being No. 238 Brinell. It will be seen that the $\frac{7}{8}$-in. hole was drilled at a feed rate of 15 in. per minute, and the $\frac{1}{4}$-in. hole at 50 in. per minute. These speeds are remarkable, but would hardly ever be attempted on general work under ordinary conditions.

CAST IRON.			MILD STEEL.		
Diameter of Drill.	Speed of Drill.	Time to Drill 1 in. deep.	Diameter of Drill.	Speed of Drill.	Time to Drill 1 in. deep.
¼	2,050	1⅕ seconds	¼	2,050	2⅖ seconds
5/16	1,370	1½ ,,	5/16	2,050	2⅖ ,,
⅜	900	2 ,,	⅜	900	3⅖ ,,
7/16	900	2 ,,	7/16	900	3⅗ ,,
½	900	2 ,,	½	900	4 ,,
9/16	600	2½ ,,	9/16	900	5 ,,
⅝	600	2½ ,,	⅝	900	5⅗ ,,
11/16	600	2½ ,,	11/16	900	5⅘ ,,
¾	600	3 ,,	¾	900	6 ,,
13/16	600	3 ,,	13/16	900	7 ,,
⅞	600	4 ,,	⅞	900	7⅕ ,,

Lubrication.—The use of a good flow of lubricant when drilling undoubtedly prolongs the life of a drill to a great extent. When drilling iron and steel, a mixture of soft soap, soda, and water will enable the drill to be run at greatly increased speeds and feeds if applied quite freely.

Hand Drilling.—Hand drilling is frequently necessary, chiefly in repair work. For this purpose various appliances for holding the ratchet and drill are provided. The most common form is the drill post shown in Fig. 59. This consists of a base plate to which is welded a vertical spindle, which carries a movable arm. The base is drilled or slotted in several places to take bolts for fixing, or it can be held by means of a boiler screw or cramp. The arm can then be swivelled into any position desired, and adjusted to the height required.

The ratchet is generally fitted with a square tapered hole to take a square shank drill.

Portable Hand Drilling Machines are made and designed to work by means of pneumatic and electrical power, and will do work enormously quicker than is possible with the ratchet brace. Holes up to ½ inch in diameter can be drilled by means of these drills by simply using a breastplate, but over that diameter a fixture must be set up to work in conjunction with a feed wheel and spindle. In both these types of drills, electric and pneumatic, it is necessary to have main power supply, which must be conveyed to the machine through a cable or by means of armoured hose.

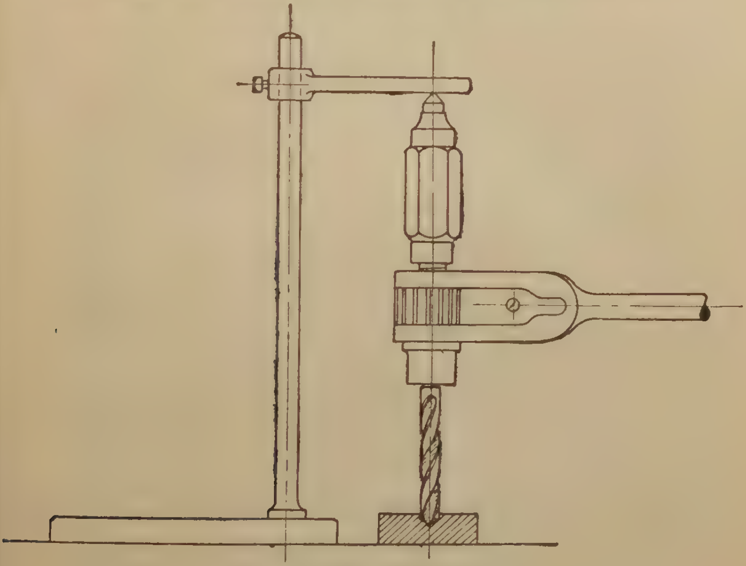


FIG. 59.—Hand Drilling.

It is also possible to adjust these machines to do work such as reaming and tapping.

The magnetic drill post is a most useful tool for repair work. By simply placing the drill post against the plate or job to be drilled, and then switching on the current, the post can be held in any position required.

Decimal Equivalents of the Numbers of Twist Drill and Steel Wire Gauge

No.	Size of Number in Decimals.	No.	Size of Number in Decimals	No.	Size of Number in Decimals.	No.	Size of Number in Decimals.
1	·2280	21	·1590	41	·0960	61	·03900
2	·2210	22	·1570	42	·0935	62	·03800
3	·2130	23	·1540	43	·0890	63	·03700
4	·2090	24	·1520	44	·0860	64	·03600
5	·2055	25	·1495	45	·0820	65	·03500
6	·2040	26	·1470	46	·0810	66	·03300
7	·2010	27	·1440	47	·0785	67	·03200
8	·1990	28	·1405	48	·0760	68	·03100
9	·1960	29	·1360	49	·0730	69	·02925
10	·1935	30	·1285	50	·0700	70	·02800
11	·1910	31	·1200	51	·0670	71	·02600
12	·1890	32	·1160	52	·0635	72	·02500
13	·1850	33	·1130	53	·0595	73	·02400
14	·1820	34	·1110	54	·0550	74	·02250
15	·1800	35	·1100	55	·0520	75	·02100
16	·1770	36	·1065	56	·0465	76	·02000
17	·1730	37	·1040	57	·0430	77	·01800
18	·1695	38	·1015	58	·0420	78	·01600
19	·1660	39	·0995	59	·0410	79	·01450
20	·1610	40	·0980	60	·0400	80	·01350

CHAPTER VI

MILLING

The operation of milling, or the cutting of metal by means of revolving mills, has become of great importance in recent years. To a large extent the milling machine has displaced the planer and the shaper, and to a smaller degree even the lathe. The great obstacle to the more general use of the milling machine has been the initial cost and upkeep of cutters. It has been the practice for some firms to make their own, and this, often having to be done by hand, proved a very expensive method. Since high-speed cutters of crucible cast steel have been on the market at a reasonable cost, with a guarantee of cutting power, and an offer to replace all defective cutters, the use of the milling machine has increased to a remarkable extent.

With all its advantages for rapid and economical shaping of metals, there are some operations which can still be done cheaper and quicker by means of the planer and shaper, and it will be some considerable time before the use of those machines is entirely abandoned.

It is owing to the increasing importance of milling machines, and their extended and more general use, that so many pages are being devoted to illustrating the various operations that can be performed by this type of machine tool.

The advantages of milling over other methods of machining is due to the fact that exact reproduction of intricate forms can be obtained quite automatically and independent of the operator, and when a large number of parts are to be produced in duplicate, this is, of course, of supreme importance to the manufacturer.

Milling Machines.—A machine which operates upon and cuts metal by means of rotating cutters might be termed a milling machine. The most common types in general use are the plain, vertical, and universal.

Plain Milling Machines.—These machines can be used for a great variety of general milling work. They are made to be easily and quickly adjusted, and are of special use in small shops for general and jobbing work. They are arranged, as a rule, in such a manner that the table and work can be fed automatically or by hand in either direction horizontally, the table being lifted or lowered by hand only. The table is arranged to move at right angles to the arbor of the machine, and cannot be swivelled in any way.

Vertical Milling Machines.—The vertical milling machine is designed so that the spindle which carries the cutter revolves and cuts while rotated in a vertical position, the work being fed horizontally, vertically, or by a circular motion to the cutter.

One of the most modern type of vertical milling machines is illustrated in Fig. 60. This is one of Messrs Alfred Herbert's patent vertical milling and profiling machines, and shows it carrying out a heavy face milling operation.

The principal features of this machine are the special provisions made for automatic vertical movements, which can be adjusted slow or quick; the provision for attaching large surfacing cutters to the spindle nose direct; the fact that all gears are enclosed, and all movements governed by convenient hand wheels, with adjustable index discs to all motions; automatic stops to all feeds, with the longitudinal

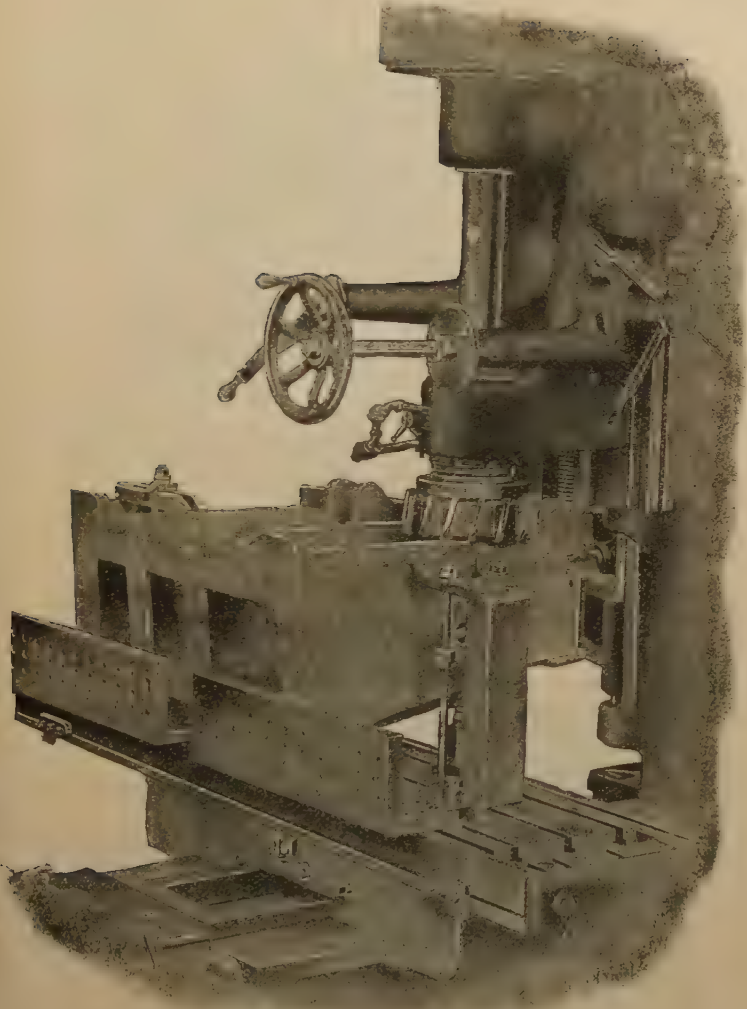


FIG. 60.—Vertical Milling Machine.

and cross-feed nuts made adjustable for wear, and fitted with ball thrusts to the feed screws.

For circular work, a circular table with automatic feed in either direction, and automatic stops, is fitted to the machine. A rotating square table, which can be used for bulky work which cannot be covered by the traverses of the machine, can also be fitted to the table, and by means of this attachment one side of a piece of work can be milled, and the table rotated through 90° or 180° as required to do the other sides.

Examples of Vertical Milling Work

The following illustrations are taken from work done by one of Messrs Alfred Herbert's vertical milling machines.

Recessing.—An example of the use of the end mill is shown in Fig. 61. This illustrates the method of using the end mill for cutting out recessed portions of castings, and for general work of a similar character. A great amount of work can be accomplished in this manner that can be done in no other way. The actual job being performed is the chasing saddle of a combination turret lathe.

Face Milling.—The illustration, Fig. 62, shows the use of a face cutter on work having a number of facings to be machined at different levels.

The casting shown being operated upon is the feed box of a capstan lathe, and there are five facings to be milled off at three different levels. Such work is very rapidly performed on vertical milling machines.

Facing with Vertical Mill.—Fig. 63 shows a very good example of facing work by means of a spiral side mill. Very rapid and accurate work can be turned out by this arrangement.

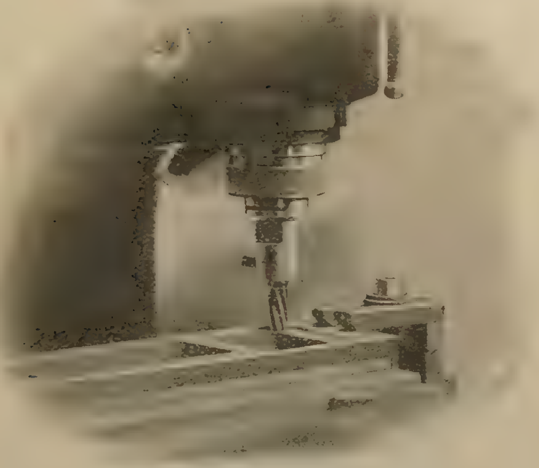


FIG. 61.—Recessing with an End Mill.

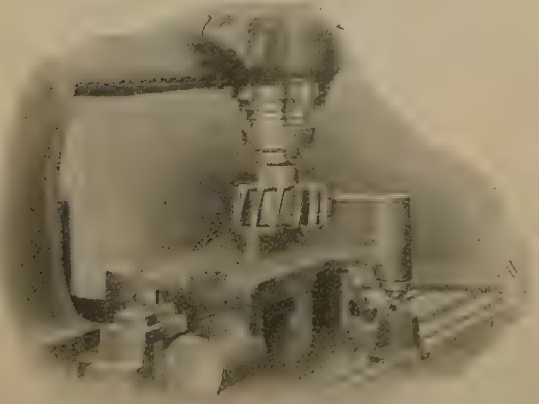


FIG. 62.—Milling at Different Levels.

Slot Milling.—An example of slot milling is shown in Fig. 64. By adopting this method for slotting work, it is possible to do jobs which would otherwise have to be done on drilling and slotting machines. The vertical milling machine does the work from the solid at one operation, and leaves a finish much better than that produced by drilling and slotting, and, of course, very much quicker.

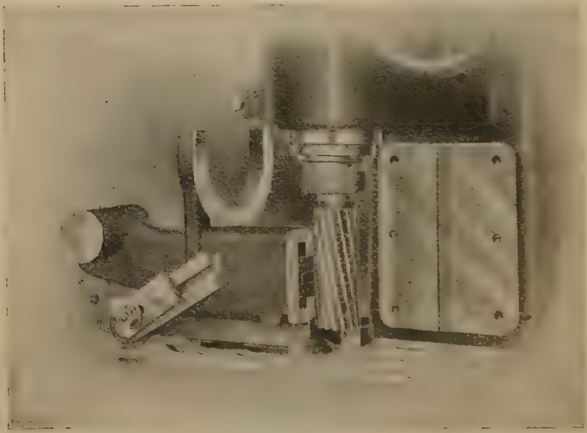


FIG. 63.—Facing with Vertical Mill.

Heavy Face Milling.—The illustration, Fig. 65, shows an example of heavy face milling. The cutter is 12 in. in diameter, arranged to attach direct to the spindle nose of the machine, and fitted with inserted cutters made from high-speed steel. This cutter will cut at 75 ft. per minute, taking a feed of $7\frac{1}{2}$ in. per minute, with a depth of $\frac{5}{32}$ in. and a width of 11 in.

Circular Recessing.—Fig. 66 shows the operation of circular recessing. By fixing the work to a revolving table, a large amount of work of this character can be done in a rapid and accurate manner.

Circular Milling.—A simple example of circular milling is illustrated in Fig. 67. The work, as can be seen, is a clutch fork, two of which are lying on the circular table. Wrought-iron and steel levers, crossheads, and rod ends are examples of similar work.

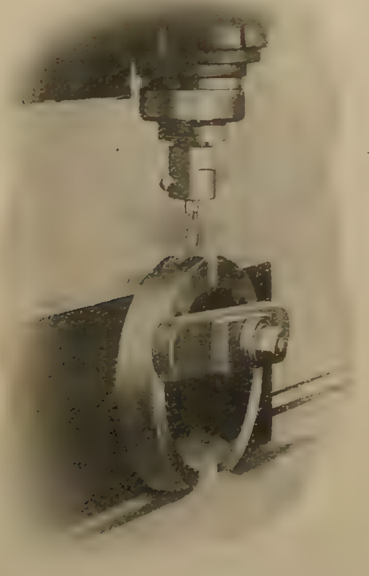


FIG. 64.—Slot Milling.

Fig. 68 illustrates the vertical milling machine fitted up for face milling a large casting.

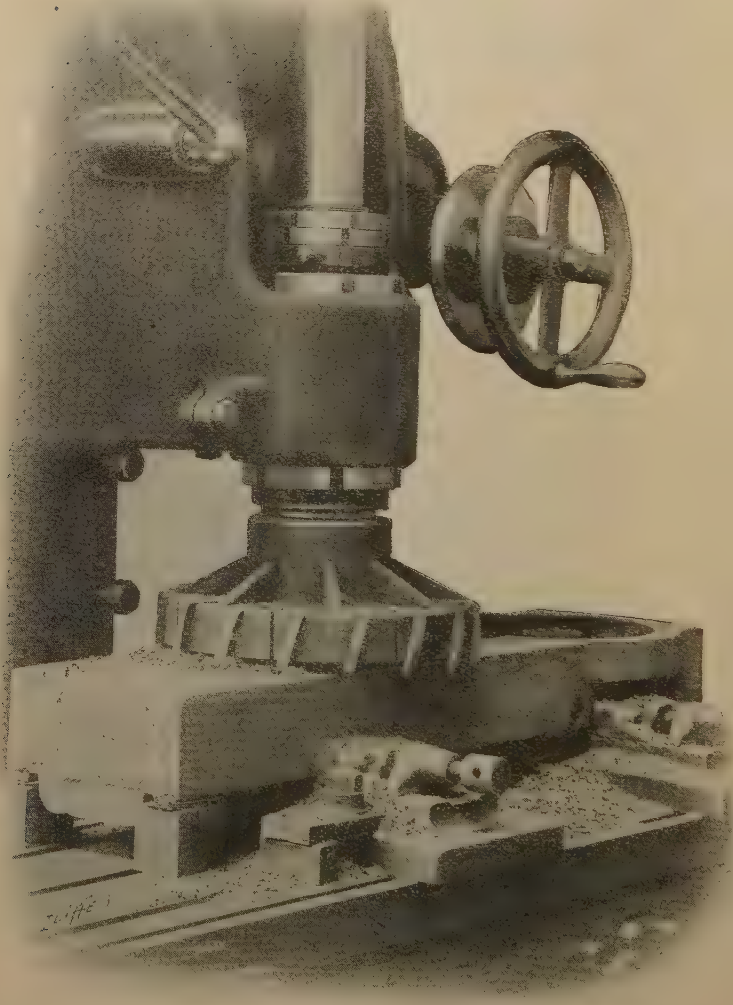


FIG. 65.—Heavy Face Milling.

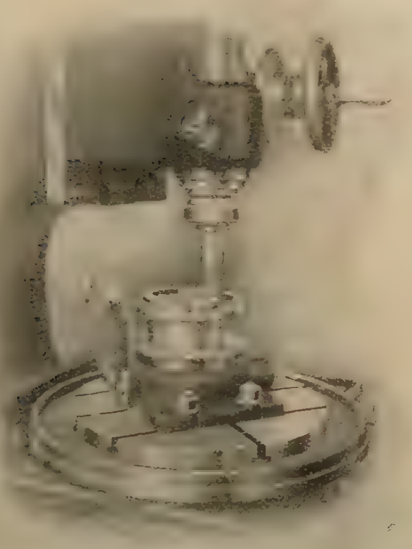


FIG. 66.—Recessing.

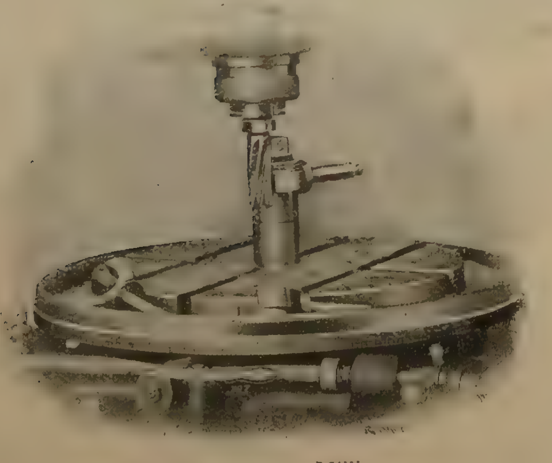


FIG. 67.—Circular Milling.

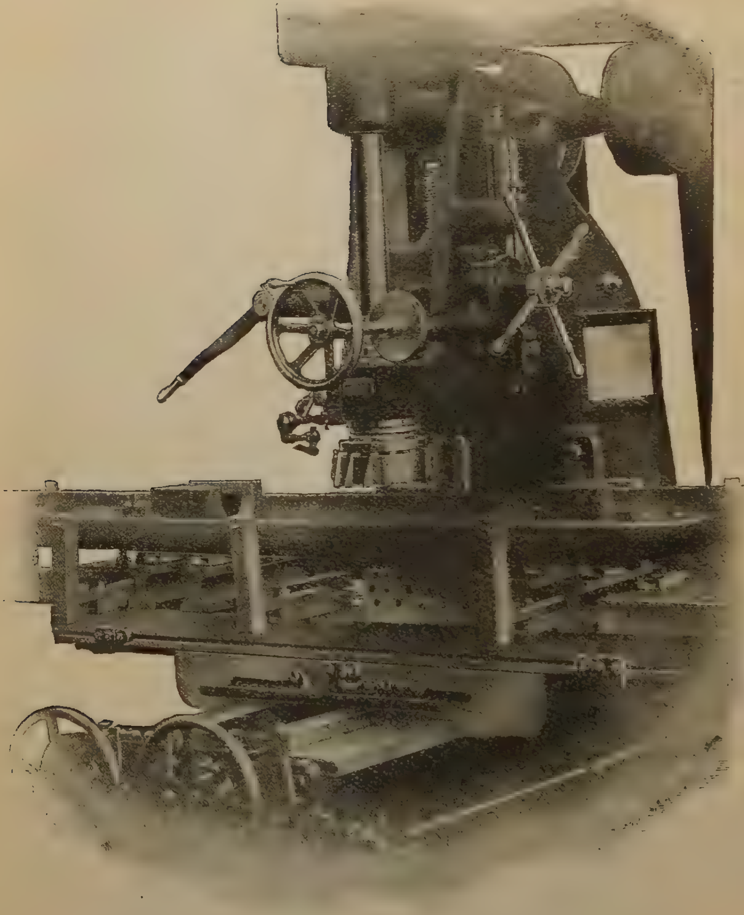


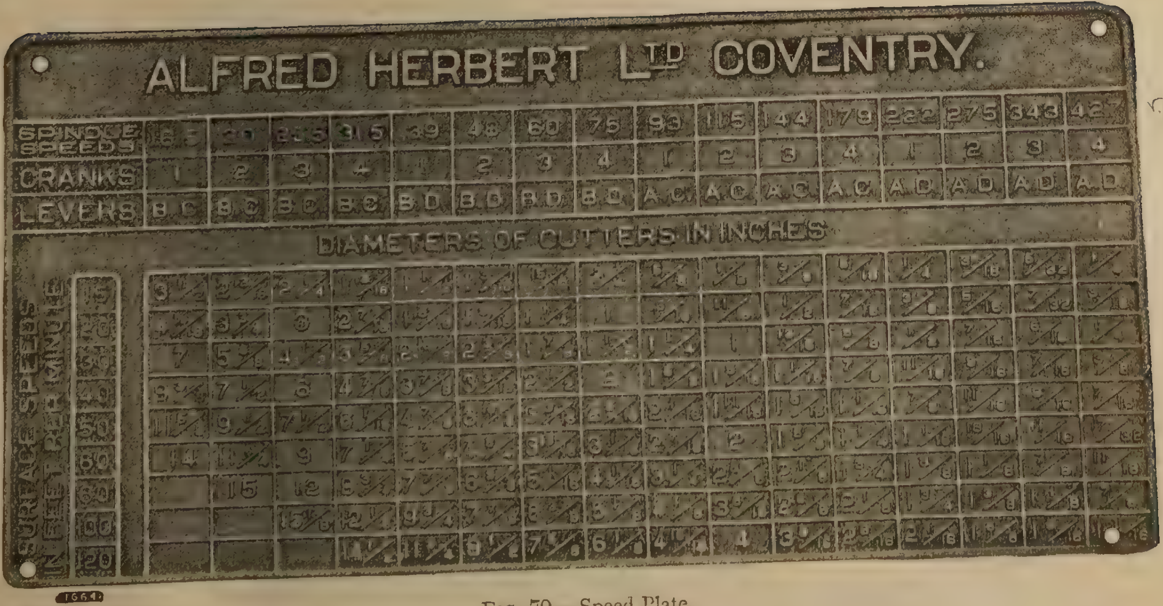
FIG. 68.—Vertical Milling.

Horizontal Milling Machines

The horizontal milling machine shown in Fig. 69 is one by Alfred Herbert, and is constructed to take work 42 in. × $13\frac{1}{2}$ in. × 21 in., and is intended for work demanding great durability, in conjunction with a large output. *The Column* is a massive dry sand-box casting in one piece with the base, and the upper portion carries the spindle and overhanging arm. The base is lipped all round, forming a pan. The vees forming the vertical slide are at an angle of 45°, thus giving a large wearing surface. They extend to the top of the column, and form a rigid means for carrying the vertical milling and other attachments.

The Driving Box is built as a separate unit, and can be removed bodily if required. It contains all the driving gears, except the two which are keyed tightly upon the spindle. There are sixteen spindle speeds in either direction in geometrical progression, and all speed changes are made by sliding gears, no tumbler mechanism and no sliding yokes or locking levers carrying the stress of driving being employed. The fact that there are no loose fits on the spindle renders the machine particularly free from chatter and vibration. The driving gears on the spindle are in all cases larger than the cutter which is being used; this feature, together with the fact that they are absolutely tight on the spindle, gives a very smooth drive. There are no dangerous points at which the gears can lock each other while being changed. The gears all run at moderate tooth velocities, and as they are of steel, case-hardened on the teeth, they are very durable. The levers by which the speed changes are made are of steel, and easily understood indicator plates are provided to show how any speed can be obtained.

The Speed Plate, which is shown in Fig. 70, indicates how to obtain any speed, and also enables the proper surface



ALFRED HERBERT LTD COVENTRY.

SPINDLE SPEEDS	[illegible]	20	25.5	31.5	39	48	60	75	93	115	144	179	222	275	343	42
CRANKS	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
LEVERS	B C	B C	B C	B C	B D	B D	B D	B D	A C	A C	A C	A C	A D	A D	A D	A D

DIAMETERS OF CUTTERS IN INCHES

SURFACE SPEEDS IN FEET PER MINUTE

15
20
30
40
50
60
80
100
120

r.p.m.

FIG. 70.—Speed Plate.

speed for different sized cutters to be read off by inspection. The plate is a great time-saver, and its use is quite self-evident.

The Arbor Support and Spindle.—The arbor support carries a bush-bearing for standard long arbors. It has, in addition, a dead centre with screw adjustment for use with small arbors or solid cutters. The dead centre is shown in position in Fig. 71. The spindle is of hardened steel, and runs in adjustable conical bearings at the front, and adjustable parallel bearings at the back. The bearings are of phosphor bronze, and the thrust is taken on hard steel and white metal washers. The spindle is bored

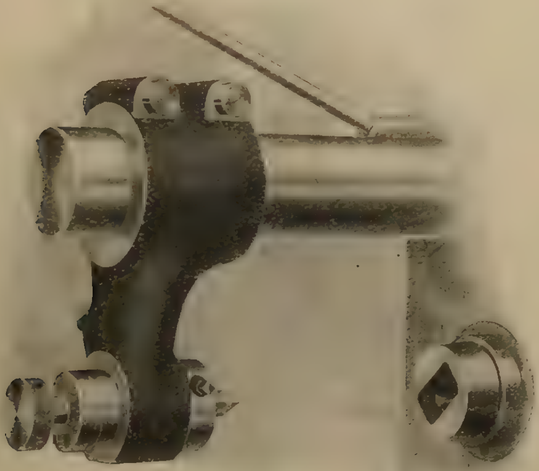


FIG. 71.—Arbor Support and Dead Centre.

through, and has a powerful box-clutch drive. The spindle nose is tapered externally, the angle being such

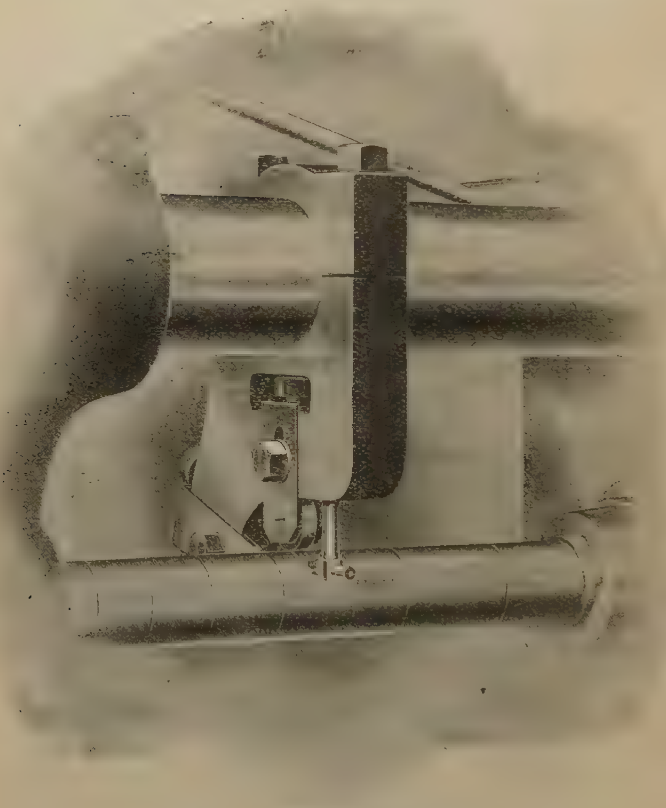


FIG. 72.—Patent Roller Steady.

that cutters of large diameters may be fixed upon it so as to run true and yet without jamming. It has been found that threaded noses, even when made with multiple threads, are liable to jam, and are therefore not suitable for the heavy class of work which can be done on these machines.

Roller Steady.—The device shown in Fig. 72 can be clamped to the overhanging arm, and can be swung out of the way when not in use. It is a great convenience on many classes of work, and it can be applied or taken away without removing the cutters from their arbors—a very valuable feature on repetition work, where gangs of cutters are kept permanently on their arbor and yet require a central support. As the roller steady does not occupy any space below the arbor, the smallest possible cutters can be employed.

The Overhanging Arm is clamped by a powerful lever from the front of the knee. It is a solid steel bar accurately ground to size. The lever can be adjusted into various positions to suit the convenience of the operator.

The Arm Brace.—The arm brace forms an outer bearing for the arbor, enabling the arbor support to be used as an intermediate bearing when using a gang of milling cutters on heavy work. The arm brace can be adjusted in or out along the knee to suit different lengths of arbors.

Automatic and Safety Stops.—All the feeds have automatic stops in both directions. This arrangement is shown in Fig. 73. The longitudinal feed, in addition to the ordinary stop which can be overrun when required, has two micrometer stops, giving a fine and accurate adjustment. These also act as dead stops and as safety stops at each end of the travel. The cross feed has a safety stop at each end of its movement, and the vertical feed has a safety stop to throw it out of action when the table is at the bottom.

The safety stops disengage the feed just before the end of the rated travel is reached.

The Table Drive.—The screw for actuating the table is of quick pitch and high efficiency. It does not rotate, and is always in tension. It is not splined, and the life of the nut is therefore long. The nut is of phosphor bronze in two lengths, to give adjustment for wear. The overall length of the nut is more than nine diameters of the screw. The thrust of the feed is taken by a large ball-thrust bearing. The revolving nut is driven by wide spur gearing of high tensile steel, which is very much stronger than the weak bevel gears used on many other machines, and which will not fail under any work that can be done. The worm gear is of quick pitch and high efficiency, and the thrust of the worm is taken by a ball-thrust bearing.

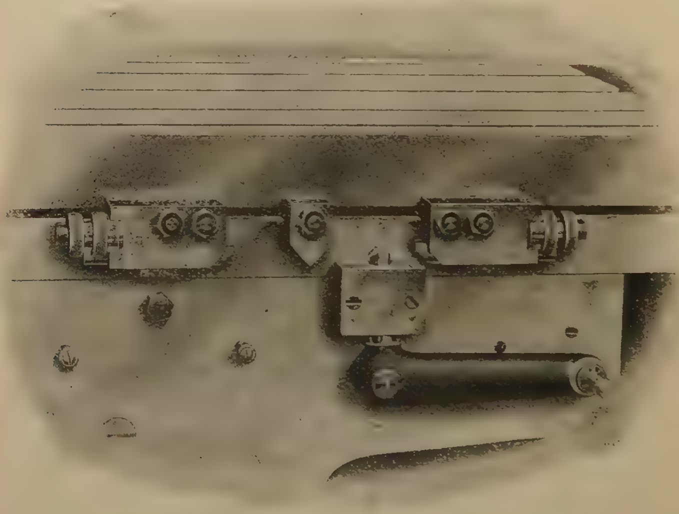


FIG. 73.—Longitudinal Feed Control, with Micrometer Stops.

The above features are the very life of a machine for heavy work, and cannot be too carefully considered.

The Automatic Cross Feed.—The automatic cross feed is engaged and released by a handle at the front of the knee, with an indicator plate to show the mode of operation. The cross-feed nut and also the thrust bearing of the cross-feed screw are adjustable for wear. The cross-feed screw is in the centre of the knee in the best position for feeding.

Universal Milling

By taking advantage of the many attachments which are provided with the universal milling machine it is possible to carry out nearly any conceivable milling operation. In addition to the automatic horizontal feed working at right angles, which is provided with the ordinary horizontal miller, it is possible on this type of machine to rotate the work, and at the same time feed forward or backward at any desired angle. It is thus possible to do such work as cutting teeth in spur wheels, fluting twist drills and reamers, cutting spiral and helical gears, cutting bevels and mitres, hobbing worm wheels, and other work of a special character.

A prominent type of universal miller is the one shown in Fig. 74. In this machine the chief characteristics are:—

The Overhanging Arm, which is a solid steel bar and carries two arbor supports.

The Table is heavy and deep, with full-width bearing on the cross slide. The feed screw is of coarse pitch and unusually large diameter.

The Knee is of box section, with bearing on column carried up beyond horizontal surface. The elevating screw is telescopic, and needs no hole in the floor. All movements are controlled by graduated index discs reading to one-thousandth of an inch.

The Feed is driven positively through spur gears, and has sixteen changes made by two levers. The feed is automatic

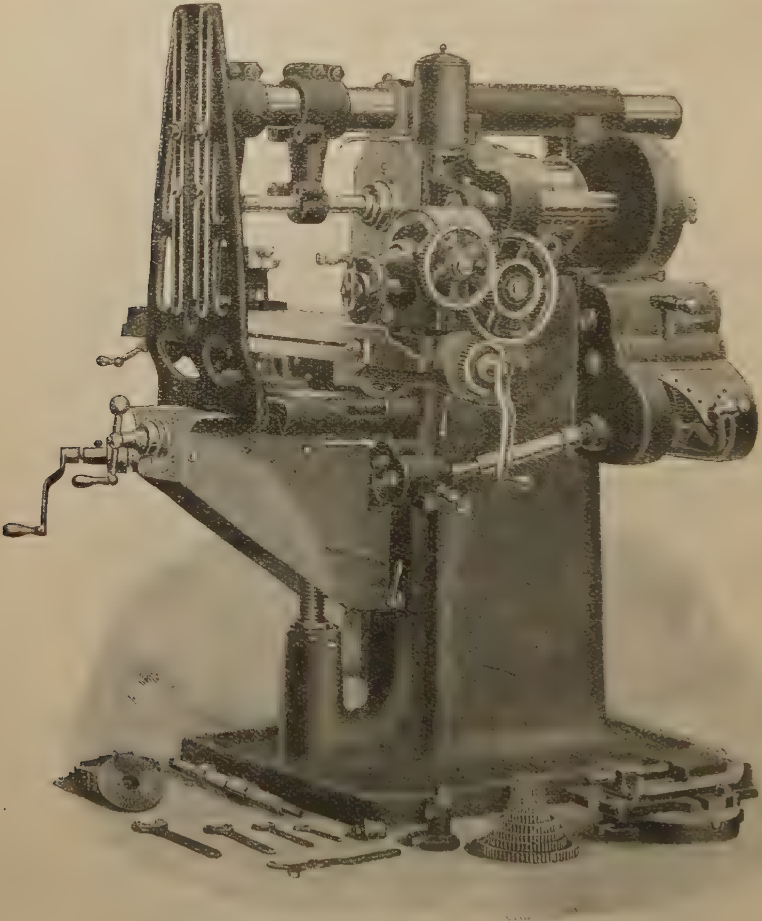


FIG. 74.—Alfred Herbert's Universal Milling Machine.

in longitudinal, cross, and vertical directions, all of which are controlled by automatic trips.

The Dividing Head can be set 10° below the horizontal each way, and is of great rigidity and accuracy. The index

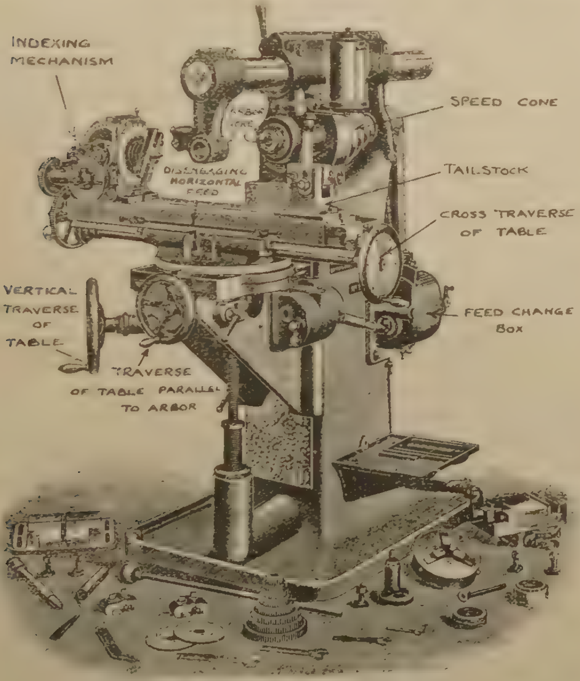

INDEXING MECHANISM
ARBOR CONE
SPEED CONE
DISENGAGING HORIZONTAL FEED
TAILSTOCK
CROSS TRAVERSE OF TABLE
VERTICAL TRAVERSE OF TABLE
FEED CHANGE BOX
TRAVERSE OF TABLE PARALLEL TO ARBOR

Fig. 75.—Brown & Sharpe Universal Milling Machine.

plates divide all numbers up to 50, all even numbers to 100, and many others up to 360. Spirals from one turn in 1.55 in. to one turn in 137.14 in. can be cut. Differential indexing divides all numbers up to 360.

Fig. 75 illustrates one of Brown & Sharpe's millers, with some of the parts marked. The construction of this machine is as follows:—

The Spindle is of crucible steel. Bearings ground. Bronze boxes provided with means of compensation for wear. Front end threaded, $2\frac{1}{2}$ in. diameter, 4 L.H. Has No. 10 taper hole. Hole through, $\frac{21}{32}$ in. diameter.

Drive.—Cone, five steps; largest, $10\frac{3}{4}$ in. diameter. 3-in. belt. Ten changes of spindle speed in geometrical progression; 44 to 310 revolutions per minute, in either direction.

Overhanging Arm.—Solid steel. Both bearings clamped with one lever. Centre of spindle to under side of arm, $5\frac{1}{2}$ in.

Arbor Support.—Bronze bushing for arbor bearing, hole $1\frac{13}{16}$ in. diameter. Adjustable centre an integral part. Greatest distance, end of spindle to centre in arbor support, 20 in.

Table.—Including oil pans and channels, $37\frac{1}{2}$ in. × $8\frac{1}{4}$ in. Working surface, $34\frac{1}{4}$ in. × $8\frac{1}{4}$ in. Two T-slots, $\frac{5}{8}$ in. wide. Quick return operated by internal gear and pinion. Arc of swing, 286°. Elevating screw, telescopic. Knee clamped by one lever on front between hand wheels.

Feeds.—Positive. All spur gears driven by chain. Twenty changes in geometrical progression, from .003 in. to .150 in. per revolution of spindle. No loose change gears. Changes made by adjustment of index slide and levers. Longitudinal, automatic, 20 in. Transverse, automatic, 7 in. Vertical, 18 in. Automatic feed can be used with table set at any angle to 53° either side of 0. Feed tripping mechanism, double plunger type. Sensitive. Can be set to prevent throwing in of wrong clutch. Hand wheels clutched.

Spiral Heads and Footstock Centres.—Swing 10 in.

diameter, take 17 in. Head can be set at any angle from 10° below horizontal to 5° beyond perpendicular. Graduated to half degrees. Front end of spindle threaded $2\frac{1}{4}$ in. diameter, $4\frac{1}{2}$ R.H. Has No. 10 taper hole. Hole through, $1\frac{1}{16}$ in. diameter. Footstock centre adjustable in vertical plane. Index crank adjustable. Sector arms graduated.

Differential Indexing.—All divisions from 1 to 382.

Adjustable Dials.—Graduated to thousandths of an inch.

Vice.—Swivels. Graduated base. Jaws hardened, $5\frac{1}{8}$ in. wide, $1\frac{1}{4}$ in. deep, open $2\frac{3}{4}$ in.

Countershaft.—Driven by one pulley, 14 in. diameter. 3-in. belt. 130 r.p.m. Two speeds in either direction obtained by gearing in countershaft.

Indexing

The object of indexing is to divide the periphery of a piece of work into an equal number of parts, and thus enable the milling machine to do such work as gear cutting. For this purpose the miller is fitted with a dividing head, which may be plain or universal.

With the plain dividing head, as illustrated in Figs. 76 and 77, it is possible, by having a number of division plates, to divide work into any number of parts. The spindle of this type of head is fitted with a clutch drive, and has a taper hole. The division plates are fixed so that there is no danger of the plate moving after the work is set. The indexing bolt has a movable end, which can be changed to suit different forms of notches. The $7\frac{1}{4}$-in. head has a removable support for taking the thrust of the cutter when cutting large spur wheels. This direct method of indexing can only be applied to the universal type of head when provision is made for dropping the worm out of gear, or where it is possible to disengage the worm wheel. The index plate is generally fitted to the front of the spindle, and usually contains twenty-four holes or notches, equally

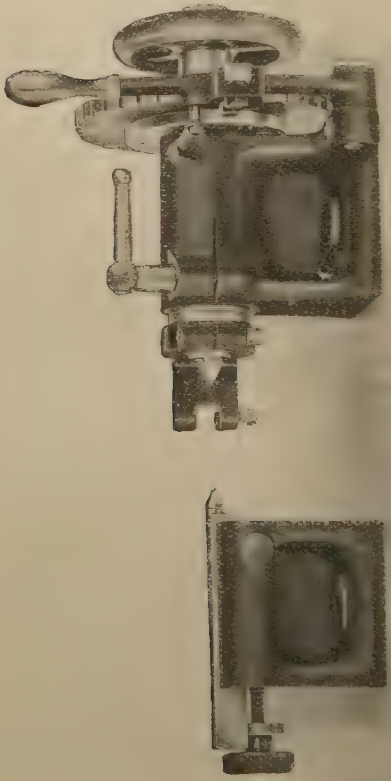


FIG. 76.—Plain Dividing Head, 4¾ in.

divided. Into any of these holes or notches a pin can be inserted, and the spindle can then be locked in that position.

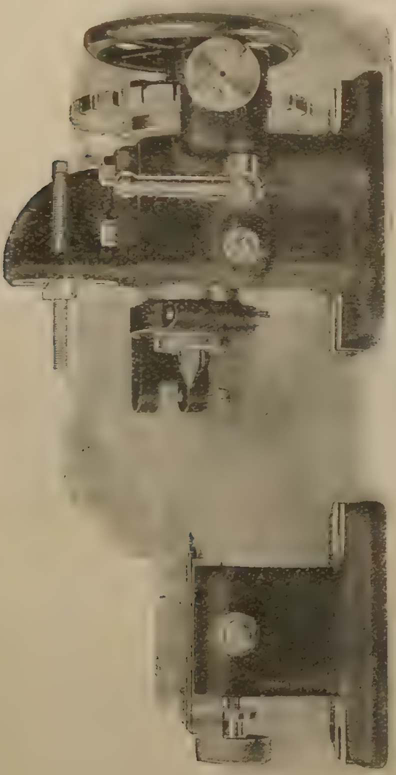


FIG. 77.—Plain Dividing Head, 7¼ in.

Thus, with a plate having 24 divisions, it is possible to divide work into equal divisions of 2, 3, 4, 6, 8, 12, and 24 parts by a very simple and reliable method.

The Universal Dividing Head

By using the universal dividing head it is possible, by taking advantage of the worm gearing, to divide work into a great number of equal parts. One of these types of head is shown in Fig. 78. This method of dividing is termed indirect indexing.

The Indirect Method.—All indirect methods of indexing depend upon the ratio of the worm gear. This is generally 40 to 1, so that 40 turns of the worm are necessary to produce 1 turn of the spindle. If only a fraction of a turn of the work is required, then only a fraction of 40 turns will need to be given to the worm through the indexing handle. As the indexing spindle may be revolved by the crank, and as 40 turns of the crank make 1 revolution of the spindle, to find how many turns of the crank are necessary for a certain division of work, or what is the same thing, for a certain division of a revolution of the spindle, 40 is divided by the number of divisions which are desired. The rule

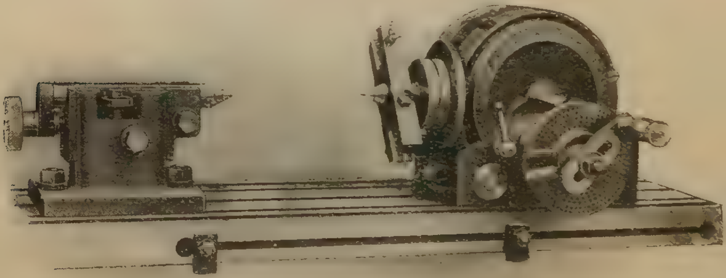


Fig. 78.—Universal Dividing Head.

then is: *Divide* 40 *by the number of divisions to be made, and the quotient will be the number of turns of the crank.*

Applying the Rule.—To make 40 divisions, the crank would be turned round once to obtain each division, or to obtain 20 divisions it would be turned round twice. When it is necessary to turn the crank only part of a turn to obtain the necessary divisions, an index plate is used.

Example.—If the work is to be divided into 80 divisions, the crank must be turned half-way round, and an index plate with an even number of holes in one of the circles would be selected, it being necessary to have two holes opposite each other in the plate. If the work is to be divided into 120 divisions, an index plate should be selected which has a circle with a number of holes that will divide by three, such as 15, 18, or 21, the number on the index plate indicating the number of holes in the various circles.

The Sector.—The sector is used to avoid the counting of the holes in each partial rotation or turn of the crank, and to illustrate its use, suppose it is necessary to divide a piece of work into 144 divisions. Dividing 40 by 144 we get $\frac{5}{18}$, showing that the crank must be moved $\frac{5}{18}$ of a turn to obtain each of the 144 divisions. An index plate with a circle containing 18 holes or an aliquot part of 18 is selected, and the sector is set to measure off six spaces on an 18 circle, or eleven on a 36 circle. When the sector is set, it is secured by means of a screw. In setting the sector it should be remembered that there must always be more holes between the arms than there are spaces to be counted or measured off. After making one division the sector is moved round until the arm is against the pin in the crank.

If the angle of elevation of the spiral head spindle is changed during the progress of the work, the work must be rotated slightly to bring it back to the proper position, as when the spindle is elevated or depressed the worm wheel is rotated about the worm, and the effect is the same as if the worm were turned in the opposite direction.

INDEX TABLE FOR USE WITH THE DIVIDING HEAD OF MILLING MACHINE

Number of Divisions.	Number of Holes in the Index Circle.	Number of Turns of the Crank.	Number of Divisions.	Number of Holes in the Index Circle.	Number of Turns of the Crank.
2	Any	20	35	49	$1\frac{7}{49}$
3	39	$13\frac{13}{39}$	36	27	$1\frac{3}{27}$
4	Any	10	37	37	$1\frac{3}{37}$
5	,,	8	38	19	$1\frac{1}{19}$
6	39	$6\frac{26}{39}$	39	39	$1\frac{1}{39}$
7	49	$5\frac{35}{49}$	40	Any	1
8	Any	5	41	41	$\frac{40}{41}$
9	27	$4\frac{12}{27}$	42	21	$\frac{20}{21}$
10	Any	4	43	43	$\frac{40}{43}$
11	33	$3\frac{21}{33}$	44	33	$\frac{30}{33}$
12	39	$3\frac{13}{39}$	45	27	$\frac{24}{27}$
13	39	$3\frac{3}{39}$	46	23	$\frac{20}{23}$
14	49	$2\frac{42}{49}$	47	47	$\frac{40}{47}$
15	39	$2\frac{26}{39}$	48	18	$\frac{15}{18}$
16	20	$2\frac{10}{20}$	49	49	$\frac{40}{49}$
17	17	$2\frac{6}{17}$	50	20	$\frac{16}{20}$
18	27	$2\frac{6}{27}$	52	39	$\frac{30}{39}$
19	19	$2\frac{2}{19}$	54	27	$\frac{20}{27}$
20	Any	2	55	33	$\frac{24}{33}$
21	21	$1\frac{19}{21}$	56	49	$\frac{35}{49}$
22	33	$1\frac{27}{33}$	58	29	$\frac{20}{29}$
23	23	$1\frac{17}{23}$	60	39	$\frac{26}{39}$
24	39	$1\frac{26}{39}$	62	31	$\frac{20}{31}$
25	20	$1\frac{12}{20}$	64	16	$\frac{10}{16}$
26	39	$1\frac{21}{39}$	65	39	$\frac{24}{39}$
27	27	$1\frac{13}{27}$	66	33	$\frac{20}{33}$
28	49	$1\frac{21}{49}$	68	17	$\frac{10}{17}$
29	29	$1\frac{11}{29}$	70	49	$\frac{28}{49}$
30	39	$1\frac{13}{39}$	72	27	$\frac{15}{27}$
31	31	$1\frac{9}{31}$	74	37	$\frac{20}{37}$
32	20	$1\frac{5}{20}$	75	15	$\frac{8}{15}$
33	33	$1\frac{7}{33}$	76	19	$\frac{10}{19}$
34	17	$1\frac{3}{17}$	78	39	$\frac{20}{39}$

INDEX TABLE FOR USE WITH THE DIVIDING HEAD OF MILLING MACHINE—*continued.*

Number of Divisions.	Number of Holes in the Index Circle.	Number of Turns of the Crank.	Number of Divisions.	Number of Holes in the Index Circle.	Number of Turns of the Crank.
80	20	$\frac{10}{20}$	164	41	$\frac{10}{41}$
82	41	$\frac{20}{41}$	165	33	$\frac{8}{33}$
84	21	$\frac{10}{21}$	168	21	$\frac{5}{21}$
85	17	$\frac{8}{17}$	170	17	$\frac{4}{17}$
86	43	$\frac{20}{43}$	172	43	$\frac{10}{43}$
88	33	$\frac{15}{33}$	180	27	$\frac{6}{27}$
90	27	$\frac{12}{27}$	184	23	$\frac{5}{23}$
92	23	$\frac{10}{23}$	185	37	$\frac{8}{37}$
94	47	$\frac{20}{47}$	188	47	$\frac{10}{47}$
95	19	$\frac{8}{19}$	190	19	$\frac{4}{19}$
98	49	$\frac{20}{49}$	195	39	$\frac{8}{39}$
100	20	$\frac{8}{20}$	196	49	$\frac{10}{49}$
104	39	$\frac{15}{39}$	200	20	$\frac{4}{20}$
105	21	$\frac{8}{21}$	205	41	$\frac{8}{41}$
108	27	$\frac{10}{27}$	210	21	$\frac{4}{21}$
110	33	$\frac{12}{33}$	215	43	$\frac{8}{43}$
115	23	$\frac{8}{23}$	216	27	$\frac{5}{27}$
116	29	$\frac{10}{29}$	220	33	$\frac{6}{33}$
120	39	$\frac{13}{39}$	230	23	$\frac{4}{23}$
124	31	$\frac{10}{31}$	232	29	$\frac{5}{29}$
128	16	$\frac{5}{16}$	235	47	$\frac{8}{47}$
130	39	$\frac{12}{39}$	240	18	$\frac{3}{18}$
132	33	$\frac{10}{33}$	245	49	$\frac{8}{49}$
135	27	$\frac{8}{27}$	248	31	$\frac{5}{31}$
136	17	$\frac{5}{17}$	260	39	$\frac{6}{39}$
140	49	$\frac{14}{49}$	264	33	$\frac{5}{33}$
144	18	$\frac{5}{18}$	270	27	$\frac{4}{27}$
145	29	$\frac{8}{29}$	280	49	$\frac{7}{49}$
148	37	$\frac{10}{37}$	290	29	$\frac{4}{29}$
150	15	$\frac{4}{15}$	296	37	$\frac{5}{37}$
152	19	$\frac{5}{19}$	300	15	$\frac{2}{15}$
155	31	$\frac{8}{31}$	310	31	$\frac{4}{31}$
156	39	$\frac{10}{39}$	212	39	$\frac{5}{39}$
160	20	$\frac{5}{20}$	360	18	$\frac{2}{18}$

Differential Indexing.—A method of indexing known as compound indexing has been brought into use in order to obtain divisions that are prime numbers, and which cannot be obtained by direct indexing. This method is complicated, as it necessitates the use of two circles. Messrs Brown & Sharpe have patented a much simpler method of indexing than by compounding, the indexing being obtained in the same manner as in plain indexing, excepting that the spindle of the dividing head is geared to the index plate. Being geared together the movement of the dividing head spindle in relation to the index crank is positive. Thus a differential motion can be obtained that allows the indexing to be made with one circle of holes, and the index crank turned in one direction.

Ordinarily, forty revolutions of the index crank are required to make one revolution of the spindle. Therefore, if the index plate is geared to the spindle, using one idler so as to rotate the index plate one turn in the same direction as the crank, and crankpin enters the same index plate hole, the result will be the spacing number 39, for the reason that while the crank has made 40 turns and the plate 1 turn in the same direction, the crank has passed a given point only 39 times. With this same gearing, and the addition of another idler, the motion of the index plate is in the opposite direction to that of the crank, and the plate gives one revolution while the crank has made 40, resulting in the spacing number 41.

Any divisions, including fractions not obtainable with the index plate, can therefore be made up with proper gearing, and the change wheels and index usually furnished provide for all divisions from 1 to 382.

Examples of Horizontal Milling

Fig. 79 shows an example of horizontal index milling, the illustration being the cutting of notches in the locking rings of automatic screw machines. The rings are of tool steel, and are mounted in gangs in a special indexing fixture.

Two cutters are mounted upon the arbor of the machine, one being a stocking cutter and the second a formed finishing cutter of the same shape as the groove.

The table is moved transversely for finishing after the roughing cut has been taken. The ends of the arbor carrying the discs to be milled are supported by cylindrical bearings, and not by centres, giving better support and enabling much heavier milling to be done.

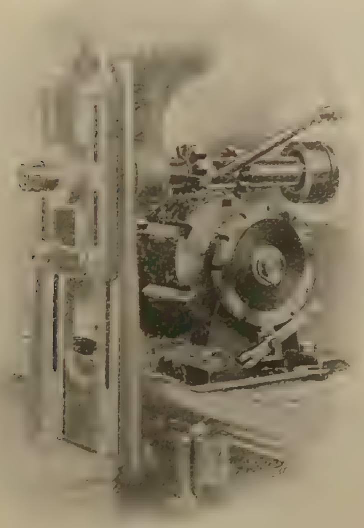


FIG. 79.—Index Milling.

The use of special fixtures is always justified where the work occurs in sufficient quantities.

Fig. 80 illustrates a gang of cutters milling the top and sides of a number of castings, using the patent steady roller shown in Fig. 72. This enables heavier feeds to be taken without springing the arbor than would be possible without it

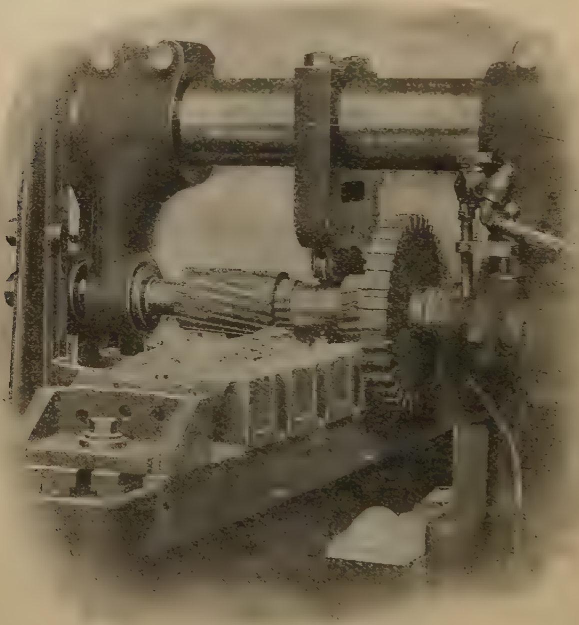


FIG. 80.—Gang Milling.

Fig. 81 shows a good example of broad milling with wide formed cutters. The work operated upon consists of conveyor links milled in gangs. This type of cutter can be sharpened without changing their form.

Speeds and Feeds

The average cutting speed for wrought iron or mild steel is about 40 ft. per minute, which would give about sixty turns per minute for mills of $2\frac{1}{2}$ in. in diameter. The feed of work for this surface speed should be about $1\frac{1}{2}$ in. per minute, and the depth of cut $\frac{1}{16}$ of an inch. In cast iron the mill can have surface speed of 50 ft. per minute, while the feed is $1\frac{1}{2}$ in. per minute, and the cut $\frac{3}{16}$ of an inch deep. In hard brass the speed may be up to 80 ft. per minute with the same feed, and the cut of $\frac{3}{32}$ of an inch deep.

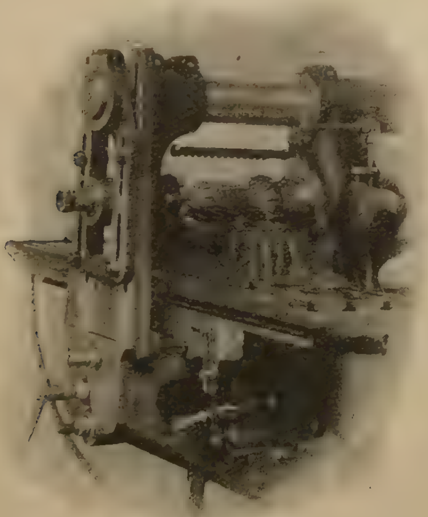


Fig. 81.—Form Milling.

It should be remembered that a small mill cuts faster than a large one. An end mill, for example, ½ inch in diameter, can be run about 400 revolutions per minute, with a feed of 4 in. per minute.

APPROXIMATE CUTTING SPEEDS AND FEEDS FOR VARIOUS METALS

Material.	Cutting Speed for Roughing.	Cutting Speed for Finishing.	Feed per Rev. Roughing.	Feed per Rev. Finishing.
	Ft. per Min.	Ft. per Min.		
Hard steel - -	20 to 30	25 to 50	0·135	0·03
Mild steel - -	30 ,, 65	50 ,, 80	0·156	0·03
Cast iron - -	20 ,, 40	35 ,, 60	0·155	0·02
Brass - - -	70 ,, 90	90 ,, 130	0·16	0·04
Tool steel - -	15 ,, 25	20 ,, 40	0·14	0·02
Wrought iron - -	35 ,, 70	80 ,, 100	0·159	0·03

SAFE SPEED FOR CUTTERS OF 6 IN. DIAMETER AND UPWARD

Steel - - -	38 ft.	per minute,	with	feed of	½	in.	per minute.
Wrought iron -	50 ,,	,,	,,	,,	1	,,	,,
Cast iron - -	60 ,,	,,	,,	,,	1⅜	,,	,,
Brass - - -	125 ,,	,,	,,	,,	2¾	,,	,,

Rule to Obtain Speed for Cutting Cast Iron.—Number of revolutions which the cutter spindle should make = 240 divided by diameter of cutter in inches.

In considering the subject of cutting speeds it should be borne in mind that rapid progress is being made in milling, and that all figures must be subjected to alteration owing to the improvements in machines, cutters, and fixtures. High-speed cutters made from air hardening steel can be speeded and fed far more rapidly than the old form of cutter.

Fixing Cutters.—Many of the smaller forms of cutters, such as T-ended cutters and end mills, are made solid with a taper or parallel shank. For larger cutters an arbor is used. This consists of a piece of steel turned taper at one end to fit the machine spindle, the opposite end being screwed to take a left hand nut. Steady bushes and distance collars are made to fit the arbor, which is also provided with a keyway running nearly the full length, the mills having a keyway also. For many jobs it will be found that the friction between the sides of the mill and the distance collar will be sufficient to prevent the mill from slipping round without the aid of a key, that is, if the teeth of the mill are quite sharp.

For holding shell mills a special shaped arbor is provided, and by using these a less expensive cutter can be adopted.

Cooling and Lubrication of Cutters.—To obtain a better finish and smoother work, it is usual to apply a mixture of soft soap, soda, and water, or lard oil, when cutting wrought iron or steel. This mixture will dissipate the greater part of the heat generated, and allow of a heavier cut than could be taken without using the cooling mixture. The water can be applied with a brush if only a small job is being milled, but for larger work a drip can is used. For very heavy milling a continuous flow of lard oil is given to the cutter by means of a pump.

CUTTING SPEEDS AND FEEDS FOR MILLING.

The following table has been arranged from actual practice by Mr R. T. Cooke, student at the London County Council School of Engineering, Poplar, London, E.

Diam. of Cutter.	Cast Iron.		Mild Steel.		Hard Steel.		Brass.	
	Speed.	Feed.	Speed.	Feed.	Speed.	Feed.	Speed	Feed.
	Revs. per Min.	Ins. per Min./Ins. per Rev.	Revs. per Min.	Ins. per Min./Ins. per Rev.	Revs. per Min.	Ins. per Min./Ins. per Rev.	Revs. per Min.	Ins. per Min./Ins. per Rev.
In.		In.		In.		In.		In.
¼	...	...	800	12/·015	600	7·2/·012	...	...
⅜	...	...	560	11·2/·02	420	6·3/·015	...	...
½	500	12/·025	400	10/·025	300	4·5/·015	875	29/·033
¾	310	9/·027	250	6·2/·025	186	2·8/·015	550	19·8/·036
1	250	8/·03	200	5/·025	150	2·5/·017	440	17·6/·04
1½	160	5/·03	128	3·4/·025	96	1·9/·02	280	11·2/·04
2	135	3·6/·03	108	2·7/·025	82	1·6/·02	235	10·7/·046
2½	95	3·2/·034	76	1·5/·02	57	·9/·016	166	7·6/·046
3	50	1·9/·037	40	·76/·019	30	·5/·016	87	4·4/·05
4	42	1·4/·034	34	·31/·013	25	·25/·01	74	3·4/·046
5	30	·6/·025	25	·26/·011	20	·2/·01	50	2/·04
6	20	·4/·02	16	·16/·01	12	·12/·01	35	1/·028

Carbon Steel.—Speeds, etc., as above, with about ⅛ in. deep cut.

High Speed Steel.—Cut ¼ in. deep; feed 1½ times the above.

Feeds.—Above feeds are maxima; reduce if desirable.

Finishing Cut.—Cut $\frac{1}{32}$ in. deep. Speed 1¼ times the above.

Broad Cuts.—Cuts over 3 in. wide, take at ¾ speed.

CUTTING SPEED TABLE.

By use of this table, the number of turns per minute for most diameters of cutters to give various cutting speeds per minute can be obtained.

Cutting Speed. Ft. per Min.	10	12	14	16	18	20	25	27½	30	35
Cutter Diam. in In.	Turns per Minute.									
¼	153	183	214	244	275	306	382	420	458	535
⅜	102	122	143	163	183	204	255	280	306	357
½	76	92	107	122	137	153	191	210	228	267
⅝	61	73	86	98	110	122	153	168	183	214
¾	51	61	71	81	92	102	127	140	153	178
⅞	44	52	61	70	79	87	109	120	131	153
1	38	46	53	61	69	76	95	105	114	134
1⅛	34	41	47	54	61	68	85	93	102	119
1¼	31	37	43	49	55	61	76	84	91	107
1⅜	28	33	39	44	50	55	69	76	83	97
1½	25	30	36	41	46	51	64	70	76	89
1¾	22	26	30	35	39	44	55	60	65	76
2	19	23	27	30	34	38	48	52	57	67
2¼	17	20	24	27	30	34	42	47	51	59
2½	15·27	18·3	21	24	27	31	38	42	46	53
2¾	13·8	16·6	19·4	22	25	28	35	38	42	49
3	12·7	15·2	17·8	20	23	25	32	35	38	44
3¼	11·7	14·1	16·4	18·8	21	23	29	32	35	41
3½	10·9	13·1	15·3	17·4	19·6	22	27	30	33	38
3¾	10·18	12·2	14·2	16·3	18·3	20·3	25	28	30	36
4	9·5	11·4	13·4	15·2	17·2	19·1	24	26	29	33
4½	8·5	10·2	11·9	13·6	15·3	17·0	21	23	25	30
5	7·6	9·2	10·7	12·2	13·7	15·27	19·1	21	23	27
5½	6·9	8·3	9·7	11·1	12·5	13·9	17·4	19·1	20·8	24
6	6·4	7·6	8·9	10·2	11·5	12·7	15·9	17·5	19·1	22
6½	5·85	7·0	8·2	9·4	10·6	11·7	14·7	16·1	17·6	20·5
7	5·45	6·5	7·6	8·7	9·8	10·9	13·6	15·0	16·4	19·1
7½	5·1	6·1	7·1	8·1	9·2	10·2	12·7	14·0	15·3	17·8
8	4·75	5·7	6·7	7·6	8·6	9·5	11·9	13·1	14·3	16·7
8½	4·5	5·4	6·3	7·2	8·1	9·0	11·2	12·3	13·5	15·7
9	4·25	5·1	5·9	6·8	7·6	8·5	10·6	11·7	12·7	14·9
9½	4·0	4·8	5·6	6·4	7·2	8·0	10·0	11·0	12·0	14·0
10	3·8	4·6	5·3	6·1	6·9	7·6	9·5	10·5	11·5	13·36
11	3·45	4·16	4·8	5·5	6·27	6·9	8·7	9·5	10·4	12·2
12	3·2	3·8	4·4	5·1	5·7	6·4	7·9	8·7	9·5	11·16
13	2·9	3·5	4·1	4·7	5·3	5·9	7·3	8·1	8·8	10·3
14	2·7	3·3	3·8	4·4	4·9	5·4	6·8	7·5	8·2	9·5
15	2·55	3·0	3·6	4·0	4·6	5·1	6·4	7·0	7·6	8·9
16	2·37	2·9	3·3	3·8	4·3	4·8	6·0	6·6	7·16	8·3
17	2·25	2·7	3·1	3·6	4·0	4·5	5·6	6·2	6·7	7·9
18	2·12	2·5	2·97	3·4	3·8	4·2	5·3	5·8	6·3	7·4
19	2·0	2·4	2·8	3·2	3·6	4·0	5·0	5·5	6·0	7·0
20	1·9	2·3	2·67	3·0	3·4	3·8	4·8	5·2	5·7	6·68
21	1·8	2·18	2·55	2·9	3·3	3·6	4·5	5·0	5·4	6·3
22	1·72	2·08	2·4	2·8	3·1	3·4	4·3	4·7	5·2	6·1
23	1·66	2·0	2·3	2·6	3·0	3·3	4·1	4·5	5·0	5·8
24	1·59	1·9	2·2	2·5	2·8	3·2	4·0	4·3	4·7	5·5

CUTTING SPEED TABLE.

By use of this table, the number of turns per minute for most diameters of cutters to give various cutting speeds per minute can be obtained.

Cutting Speed. Ft. per Min.	40	45	50	60	70	80	90	100	110	120
Cutter Diam. in In.	Turns per Minute.									
$\frac{1}{4}$	611	688	764	917	1070	1222	1375	1528	1681	1833
$\frac{3}{8}$	408	458	509	611	713	815	916	1018	1120	1222
$\frac{1}{2}$	306	344	382	458	535	611	688	764	840	916
$\frac{5}{8}$	244	275	306	367	428	489	550	611	672	733
$\frac{3}{4}$	204	229	254	306	357	407	458	509	560	611
$\frac{7}{8}$	175	196	218	262	306	349	393	436	480	523
1	153	172	191	229	267	306	344	382	420	458
$1\frac{1}{8}$	136	153	170	204	238	272	305	339	374	407
$1\frac{1}{4}$	122	138	153	183	214	244	275	305	336	366
$1\frac{3}{8}$	111	125	139	166	194	222	249	277	305	332
$1\frac{1}{2}$	102	114	127	153	178	204	229	254	280	305
$1\frac{3}{4}$	87	98	109	131	153	175	196	218	240	262
2	76	86	95	114	133	153	172	191	210	229
$2\frac{1}{4}$	68	76	85	102	119	136	153	170	187	204
$2\frac{1}{2}$	61	69	76	92	107	122	137	153	168	183
$2\frac{3}{4}$	55	62	69	83	97	111	125	139	152	166
3	51	57	64	76	89	102	115	127	140	153
$3\frac{1}{4}$	47	53	59	70	82	94	106	117	129	141
$3\frac{1}{2}$	44	49	54	65	76	87	98	109	120	131
$3\frac{3}{4}$	41	46	51	61	71	81	92	102	112	122
4	38	43	48	57	67	76	86	95	105	114
$4\frac{1}{2}$	34	38	42	51	59	68	76	85	93	102
5	30	34	38	46	53	61	69	76	84	92
$5\frac{1}{2}$	28	31	35	42	49	55	62	69	76	83
6	25	28	32	38	44	51	57	64	70	76
$6\frac{1}{2}$	23	26	29	35	41	47	53	59	65	70
7	22	25	27	33	38	44	49	54	60	65
$7\frac{1}{2}$	20·4	23	25	31	36	41	46	51	56	61
8	19·1	21	24	29	33	38	43	48	52	57
$8\frac{1}{2}$	18	20·2	22	27	31	36	40	45	49	54
9	17·0	19·1	21·2	25	30	34	38	42	47	51
$9\frac{1}{2}$	16·1	18·1	20·1	24	28	32	36	40	44	48
10	15·27	17·2	19·1	23	27	31	34	38	42	46
11	13·9	15·6	17·4	20·8	24	28	31	35	38	41
12	12·7	14·3	15·9	19·1	22	25	29	32	35	38
13	11·8	13·2	14·7	17·6	20·6	23	26	29	32	35
14	10·9	12·3	13·6	16·4	19·1	22	24	27	30	33
15	10·2	11·4	12·7	15·3	17·8	20·4	23	25	28	30
16	9·5	10·7	11·9	14·3	16·7	19·1	21·4	24	26	29
17	9·0	10·1	11·2	13·5	15·7	18·0	20·2	22	25	27
18	8·5	9·5	10·6	12·7	14·8	17·0	19·1	21	23	25
19	8·0	9·0	10·0	12·0	14·1	16·1	18·1	20	22	24
20	7·6	8·6	9·5	11·4	13·3	15·3	17·2	19	21	23
21	7·3	8·2	9·1	10·9	12·7	14·6	16·4	18	20	22
22	6·9	7·8	8·7	10·4	12·1	13·9	15·6	17·3	19	20·8
23	6·6	7·5	8·3	10·0	11·6	13·3	14·9	16·6	18·2	19·9
24	6·3	7·16	7·9	9·5	11·1	12·7	14·3	15·9	17·5	19·1

Milling Cutters

Successful milling can only be accomplished by the use of durable and correctly made cutters, which are capable of doing a considerable amount of work without the need of regrinding. The smaller cutters are generally made from the solid metal, the larger sizes having a solid shank or boss made from high carbon steel, which is recessed in a special machine designed for the purpose for the reception of cutting blades.

The solid form of cutter is a disc of high carbon steel made with the front faces of the teeth radial, giving no top rake. The angle of clearance given is 5°, the top of tooth being left about .03 of an inch wide. The tooth angle is approximately 50°. The side teeth and end teeth being formed with a 75° cutter. Cutters of this description vary from 1 to 4½ in. in diameter, and are made in widths up to 6 in.

Plain milling cutters having straight axial teeth are made up to 5 in. in diameter, but the length of tooth seldom exceeds 1 in.

The number of teeth in a cutter varies with the diameter. If the teeth of a cutter are too finely spaced there is a great tendency for the cuttings to clog in the cutter flutes, and thereby reduce the cutting efficiency. Tests made with cutters of similar diameter, having teeth of different pitch, have been made, and it is found that by reducing the number of teeth 50 per cent., the power required was reduced something like 30 per cent. It has been clearly proved that for roughing work, a coarse tooth cutter gives a saving in power, is more durable, and allows of a much heavier feed.

The following table shows the usual number of teeth and pitch given to milling cutters :—

Diameter, Inches.	No. of Teeth.	Pitch to nearest $\frac{1}{64}$ in.	Diameter, Inches.	No. of Teeth.	Pitch to nearest $\frac{1}{64}$ in.
$\frac{1}{2}$	8	$\frac{3}{16}$	$2\frac{1}{2}$	16	$\frac{1}{2}$
$\frac{3}{4}$	10	$\frac{15}{64}$	3	16	$\frac{19}{32}$
1	10	$\frac{5}{16}$	$3\frac{1}{2}$	20	$\frac{35}{64}$
$1\frac{1}{4}$	12	$\frac{21}{64}$	4	20	$\frac{5}{8}$
$1\frac{1}{2}$	12	$\frac{11}{32}$	$4\frac{1}{2}$	24	$\frac{19}{32}$
$1\frac{3}{4}$	14	$\frac{3}{8}$	5	24	$\frac{21}{32}$
2	14	$\frac{29}{64}$	$5\frac{1}{2}$	24	$\frac{23}{32}$

Types of Cutters

Milling cutters are made in various forms to perform certain classes of work, and they may be classified chiefly as angular, radial, axial, and form cutters. Figs. 82 to 88 illustrate several types of cutters in general use. The most simple type of cutter is perhaps the fly cutter. This consists of one cutter made from square or oblong section steel, with the cutting edge formed to the shape desired. As these cutters have only one cutting edge, they are easy to make, and will be found to cut very accurately. They are produced with very little expense, and may therefore be used where only one job of a particular shape is required.

Face Cutters.—Fig. 82 illustrates the ordinary type of cutter used for facing work of a general character. With these cutters one side of the job is finished at each operation. Another type of cutter used for a similar purpose consists of a cast-iron body, with hardened steel pins inserted into holes drilled in the body of the cutter, the faces of the pins being ground to form cutting edges.

Formed Cutters.—Figs. 83 and 84 show a simple type of formed cutter, one being for concave and the other for convex work. Formed cutters are made in innumerable varieties of shapes, and may be intended for such simple operations as fluting taps or twist drills, or for the most intricate reproduction work possible. It is quite common

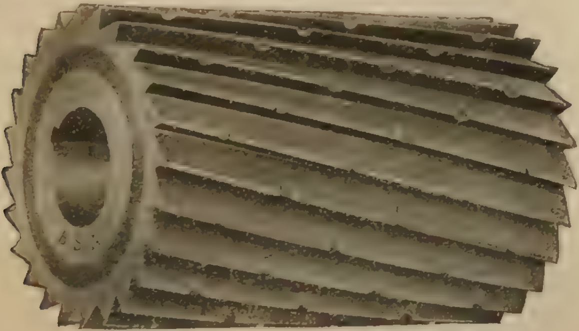


FIG. 82.—Milling Cutter, Nicked Teeth.

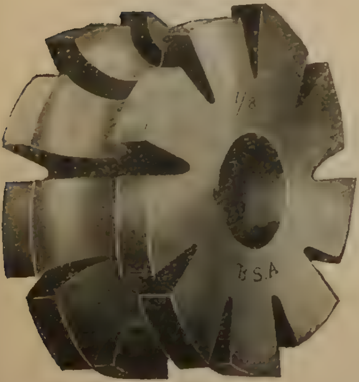


FIG. 83.—Concave Cutter.

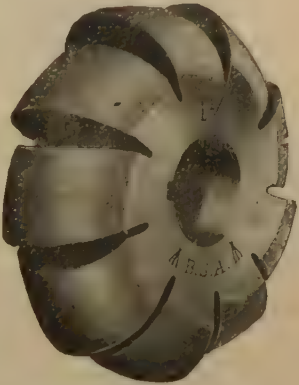


FIG. 84.—Convex Cutter.

to use formed cutters in gangs, placing one or more formed cutters with side mills on the arbor at one time, and using them collectively.

Side Milling.—For side milling or keyway cutting the mill shown in Fig. 85 is used. This type of cutter can be worked in pairs by mounting them on the arbor with a distance piece in between. By setting them up in that manner they can be used for milling two sides of a piece of work at one operation, as in the forming of the head of a bolt, and are then called straddle mills.

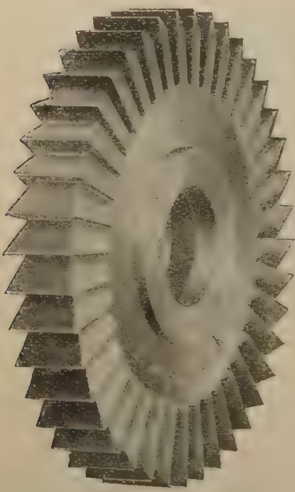


FIG. 85.—Keyway Mill.

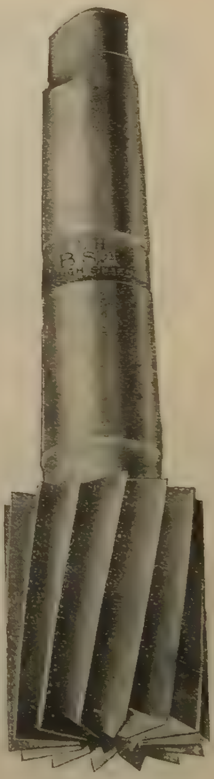


FIG. 86.—Spiral End Mill.

End Milling.—Fig. 86 shows a spiral end mill. This is a combination of the face and side milling cutter. It is used for such work as recessing, slotting, and facing.

Gear Cutters.—For cutting the teeth of spur wheels a mill similar to that shown in Fig. 87 is used.

Tee-Slot Milling.—For cutting tee-shaped slots the mill shown in Fig. 88 can be used. Before this mill is put to work it is necessary to first cut a slot with an end mill. Dovetail slots, and slots of any particular shape, can be cut in a similar manner.

To give examples of every type of milling cutter would take up too much space, but sufficient have been given to show that almost any job can be carried out in an efficient and accurate manner by means of the milling machine and well designed cutters

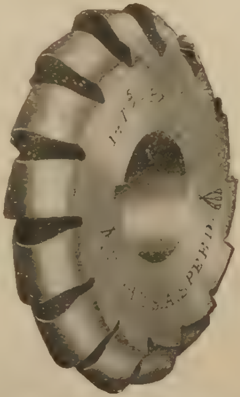


FIG. 87.—Gear Cutter.

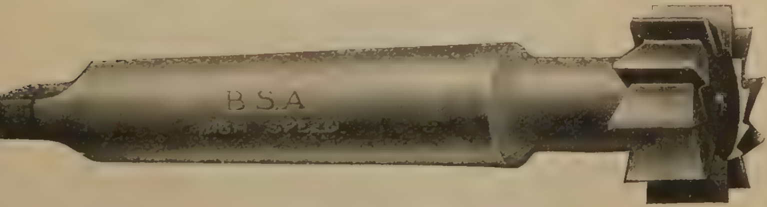


FIG. 88.—Tee-Slot Cutter.

CHAPTER VII

GEARS AND GEAR CUTTING

Owing to the great usefulness of spur, bevel, and worm gearing, and their practically noiseless running when properly designed and correctly cut, a large demand has been created for this form of power transmission, especially in the motor car industry.

Very few tooth wheels are now cast, and in cases where that method of production is still used the teeth patterns are formed in a special gear-cutting machine. The great demand for gears with machine-cut teeth has led to the introduction of many forms of gear-cutting machines, but in a large number of instances the universal milling machine will produce most of the teeth forms required.

Description of Various Gears

Spur Gears are toothed wheels, which give motion to or receive motion from a parallel shaft.

Racks are a series of teeth on a straight line, and can be considered as spur gear of infinite radii.

Internal Gear have teeth parallel to their axes and convergent to their centres, to permit pinion wheels working on their inner circumference.

Angle Gears have teeth at various degrees from their radii, but their axes are at any angle except 90°.

Bevel Gears have teeth at various degrees from their radii, their axes being at right angles to each other.

Helical and Spiral Gears have teeth or threads at any desired angle to suit the object of the drive. The axes of this gearing cannot be in the same plane—the difference being that of the radii of both spirals, or the worm and wheel as they are termed, when one is larger in diameter than the other.

Mitre Gears have teeth at an angle of 45° from their radii, their axes always being at right angles.

Pitch Lines are the rolling circumferences of two or more gears acting on each other.

Form and Proportions of Wheel Teeth

When teeth of gears form part of the body of a wheel they are termed teeth, but when separately fitted they are termed cogs.

The cycloidal form of teeth is to be preferred to involute, but the demand for machine-cut teeth has rendered its suppression to a great extent by the involute.

Cycloidal teeth are generally used for pattern gear; they can be cut approximately in a generating machine, and they can be planed, and this is done chiefly with bevel gears.

The involute is a single curve tooth, and can be generated by a cutter which possesses only a point or a plain straight line.

The Method of Drawing the Curves.—The curves may be found by rolling a templet of the size of the pitch circle inside and outside templets of the size of the pitch circle. A pencil held in contact with the rolling templet describes the required curve.

A cycloid is generated by a point in the circumference of a circle which rolls on a straight line. Fig. 89 shows one-half of the cycloid generated on a circle 1½ in. in diameter, the other half being precisely similar.

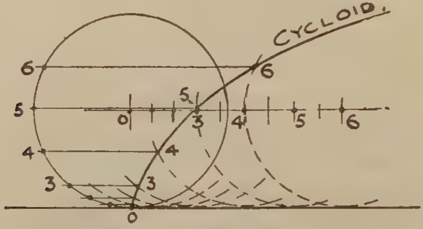
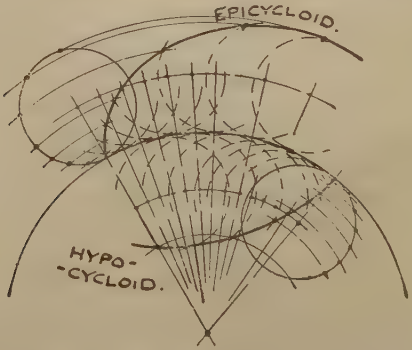


FIG. 89.—Cycloid Curve.

An epicycloid is the curve generated by a point in the circumference of a circle which rolls on the convex arc of another circle. Fig. 90 shows an epicycloid generated by a ⅞-in. circle rolling outside a 3 in. diameter circle.



FIGS. 90 and 91.—Epicycloid and Hypocycloid Curves.

Fig. 91 shows a hypocycloid curve obtained by a ⅞-in. circle rolling inside a 3-in. diameter circle.

Proportions of Wheel Teeth

Fig. 92 shows the general form of wheel teeth. In working, the faces of the teeth of one wheel come into contact with the flanks of the teeth of the other wheel.

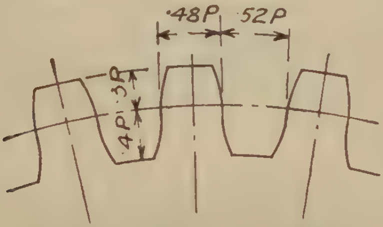


Fig. 92.—Wheel Teeth Proportions.

The proportions are—

Pitch - - - =P
Thickness of tooth - - =.48 P
Width of space - - =.52 P
Height of tooth - - =.7 P
Height above pitch line - =.3 P
Height inside pitch line - =.4 P

To compute the pitch of a wheel: Divide the circumference at the pitch line by the number of teeth.

To compute the diameter of the wheel: Multiply the number of teeth by the pitch, and divide the product by 3.1416.

To compute the number of teeth in a wheel: Divide the circumference by the pitch.

Involute Teeth

All involute wheels whose teeth have the same pitch, and the same obliquity of the line of contact, work well together, and because of the many practical advantages are generally adopted.

An involute curve can be obtained by winding a cord round a circular disc, first making a loop in the outer end of the cord, and then laying the disc flat on a sheet of paper. With a pencil in the loop unwind the string, keeping it drawn tight, and let the point of the pencil trace a curve which will be involute.

The Sizing and Cutting of Gear Wheels

Fig. 93 shows the measurements made on diametral pitch gears.

Diameter, when applied to gears, is always understood to mean pitch diameter. Diametral pitch is the number of teeth to each inch of pitch diameter.

Example.—If a gear has 40 teeth, and the pitch diameter is 4 in., there are 10 teeth to an inch of pitch diameter, and the diametral pitch is 10, or in other words, the gear is 10 diametral pitch.

Circular Pitch is the distance from the centre of one tooth to the centre of the next, measured along the pitch line.

Example.—If the distance from the centre of one tooth to the centre of the next, measured along the pitch line, is ½ in., the gear is ½ in. circular pitch.

To find Number of Teeth.—When the pitch diameter and diametral pitch are given, multiply the pitch diameter by the diametral pitch.

Example.—If the diameter of the pitch circle is 10 in., and the diametral pitch is 4, multiply 10 × 4, and the product, 40, will be the number of teeth in the gear.

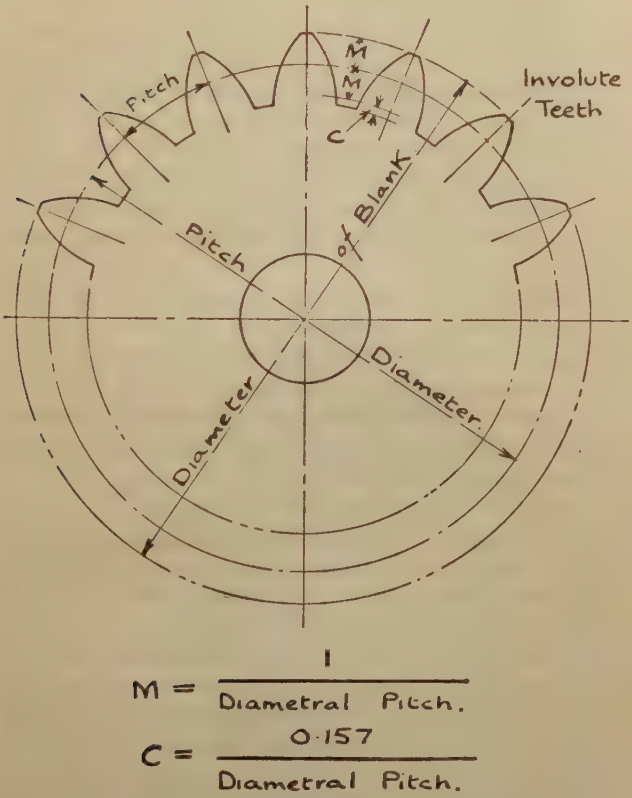


FIG. 93.—Machine-Cut Wheels, Diametral Pitch.

Diametral Pitch. — When circular pitch is given. Divide 3.1416 by the circular pitch.

Example. — If the circular pitch is 2 in., divide 3.1416 by 2, and the quotient, 1.5708, is the diametral pitch.

Diametral Pitch.—When number of teeth and outside diameter is given. Add 2 to the number of teeth, and divide by the outside diameter.

Example.—If the number of teeth is 40, the diameter of the blank 10½ in., add 2 to the number of teeth, making 42, divide by 10½; the quotient, 4, is the diametral pitch.

Circular Pitch Required.—Diametral pitch given. Divide 3.1416 by the diametral pitch.

Example.—If the diametral pitch is 4, divide 3.1416 by 4, and the quotient, .7854, is the circular pitch.

Number of Teeth Required.—Outside diameter and diametral pitch given. Multiply the outside diameter by the diametral pitch and subtract 2.

Example.—If the whole diameter is 10½ in., and the diametral pitch is 4, multiply 10½ by 4, and the product, 42 less 2, or 40, is the number of teeth.

Outside Diameter or size of gear blank required. Number of teeth and diametral pitch given. Add 2 to the number of teeth and divide by the diametral pitch.

Example.—If the number of teeth is 40, and the diametral pitch 4, add 2 to 40, making 42, and divide by 4; the quotient, 10½, is the whole diameter of the gear or blank.

Thickness of Tooth at Pitch Line.—Divide the circular pitch by 2, or 1.57 by the diametral pitch.

Example.—If the circular pitch is 1.047 in., or the diametral pitch 3, divide 1.047 by 2, or 1.57 by 3, and the quotient, .523 in., is the thickness of tooth.

Whole Depth of Tooth Required.—Divide 2.157 by the diametral pitch.

Example.—If the diametral pitch of a wheel is 6, the whole depth is 2.157 divided by 6, which equals .3595.

Distance Between Centres of Two Gears Required.—Add number of teeth together, and divide one-half of the sum by the diametral pitch.

Example.—If two gears have 50 and 30 teeth respectively and are 5 pitch, add 50 and 30, making 80 in., divide by 2, and then divide the quotient, 40, by the diametral pitch, 5, and the result, 8 in., is the centre distance.

TABLE SHOWING DEPTH OF A TOOTH TO THE PITCH LINE AND THE WHOLE DEPTH OF A TOOTH

Having the Diametral Pitch

Diametral Pitch.	Depth to Pitch Line.	Total Depth of Tooth.	Diametral Pitch.	Depth to Pitch Line.	Total Depth of Tooth.
1	1·0000	2·1571	10	0·1000	0·2157
1¼	0·8000	1·7257	11	0·0909	0·1961
1½	0·6666	1·4381	12	0·0833	0·1798
1¾	0·5714	1·2326	13	0·0769	0·1659
2	0·5000	1·0785	14	0·0714	0·1541
2¼	0·4444	0·9587	15	0·0666	0·1438
2½	0·4000	0 8628	16	0·0625	0·1348
2¾	0·3636	0·7844	17	0·0588	0·1269
3	0·3333	0·7190	18	0·0555	0·1198
3½	0·2857	0·6163	19	0·0526	0·1135
4	0·2500	0·5393	20	0·0500	0·1079
5	0·2000	0·4314	21	0·0476	0·1026
6	0·1666	0·3595	22	0·0454	0·0980
7	0·1429	0·3081	23	0·0434	0·0936
8	0·1250	0·2696	24	0·0417	0·0898
9	0·1111	0·2397			

Having the Circular Pitch

Circular Pitch.	Depth to Pitch Line.	Total Depth of Tooth.	Circular Pitch.	Depth to Pitch Line.	Total Depth of Tooth.
$\frac{1}{8}$	0·0398	0·0858	$\frac{5}{8}$	0·1989	0·4291
$\frac{3}{16}$	0·0597	0·1287	$\frac{11}{16}$	0·2189	0 4720
$\frac{1}{4}$	0·0796	0·1716	$\frac{3}{4}$	0·2387	0·5150
$\frac{5}{16}$	0·0995	0·2146	$\frac{13}{16}$	0·2586	0·5579
$\frac{3}{8}$	0·1194	0·2575	$\frac{7}{8}$	0·2785	0·6007
$\frac{7}{16}$	0·1393	0·3003	$\frac{15}{16}$	0·2984	0·6437
$\frac{1}{2}$	0·1592	0·3433	1	0·3183	0·6866
$\frac{9}{16}$	0·1790	0·3862			

Cutters for Machine-Cut Gears

The sets of cutters for involute teeth of the Brown & Sharpe system number eight, but they are often supplemented by seven half numbers for cutting an intermediate number of teeth. Eight cutters are made for each pitch.

No.	1	will cut	wheels from	135	teeth to	a rack.
,,	2	,,	,,	55	,,	134 teeth.
,,	3	,,	,,	35	,,	54 ,,
,,	4	,,	,,	26	,,	34 ,,
,,	5	,,	,,	21	,,	25 ,,
,,	6	,,	,,	17	,,	20 ,,
,,	7	,,	,,	14	,,	16 ,,
,,	8	,,	,,	12	,,	13 ,,

The half numbers are :—

No.	1½	will cut	80	to	134	teeth.
,,	2½	,,	42	,,	54	,,
,,	3½	,,	30	,,	34	,,
,,	4½	,,	23	,,	25	,,
,,	5½	,,	19	,,	20	,,
,,	6½	,,	15	,,	16	,,
,,	7½	,,	13		...	

The following table is given by Brown & Sharpe as approximate speeds for their gear cutters.

AVERAGE SPEEDS FOR GEAR CUTTERS

Diametral Pitch of Cutter.	Diameter of Cutter.	Turns per Min. for Cast Iron.	Turns per Min. for Wrought Iron and Steel.	Feed to One Turn of Cutter in Cast Iron.	Feed to One Turn of Cutter in Wrought Iron and Steel.	Feed per Min. in Cast Iron.	Feed per Min. in Wrought Iron and Steel.
	In.			In.	In.	In.	In.
2	5	24	18	0·025	0·011	0·60	0·20
$2\frac{1}{2}$	$4\frac{1}{4}$	30	24	0·028	0·013	0·84	0·31
3	$3\frac{13}{16}$	36	28	0·031	0·015	1·12	0·42
4	$3\frac{3}{8}$	42	32	0·034	0·017	1·43	0·54
5	$3\frac{1}{16}$	50	40	0·037	0·019	1·85	0·76
6	$2\frac{11}{16}$	75	55	0·030	0·016	2·25	0·88
7	$2\frac{9}{16}$	85	65	0·032	0·018	2·72	1·17
8	$2\frac{1}{2}$	95	75	0·034	0·020	3·23	1·50
10	$2\frac{1}{8}$	125	90	0·026	0·014	3·25	1·26
12	2	135	100	0·027	0·017	3·64	1·70
20	$1\frac{7}{8}$	145	115	0·029	0·021	4·20	2·41
32	$1\frac{3}{4}$	160	135	0·031	0·025	4·96	3·37

For brass, the speeds may be twice those for cast iron.

High-speed cutters may be run at from two to three times these speeds.

Cycloidal Form of Teeth

Cutters for the cycloidal form of teeth are also made so that any gear of one pitch will mesh into any other gear or into a rack of the same pitch, but twenty-four cutters are required for each pitch. In order that gears with this form of teeth shall run well together, they must be cut accurately to the required depth; otherwise the pitch circles will not be tangent to each other. To secure a proper depth of tooth, the cutters are made with a shoulder which determines the exact depth that the tooth should be cut. Thus, if care is taken when turning the blanks to obtain the correct outside diameter of the gear, no measurements need be taken when cutting the teeth. The twenty-four cutters are adapted to cut from a pinion of twelve teeth to a rack, and are designated by letters A, B, C, etc. The number of teeth and the pitch for which the cutter is adapted is always marked on each. A list of these cuttings is given in the following table:—

CUTTERS FOR CYCLOIDAL GEAR TEETH

Letter of Cutter.	No. of Teeth.	Letter of Cutter.	No. of Teeth.
A	12	M	27 to 29
B	13	N	30 ,, 33
C	14	O	34 ,, 37
D	15	P	38 ,, 42
E	16	Q	43 ,, 49
F	17	R	50 ,, 59
G	18	S	60 ,, 74
H	19	T	75 ,, 99
I	20	U	100 ,. 149
J	21 to 22	V	150 ,, 249
K	23 ,, 24	W	250 or more
L	25 ,, 26	X	Rack

Helical and Spiral Gearing

Helical and spiral gearing is a development of stepped gears, the object being to diminish the sliding action of the teeth; and a helical tooth is one in which the tooth merges into a spiral line.

In the operation of cutting a spiral in the milling machine, it is necessary to give a rotary motion as well as a longitudinal movement to the work.

The distance the helix or spiral advances in one revolution is called the lead or pitch.

To obtain the correct rotation of the work, the spiral head or indexing head of the machine is used, and the principle of obtaining the necessary change wheels is similar to that of a screw-cutting lathe. The feed to the spiral head has generally 4 threads per inch, and forty turns of the worm make one turn of the spiral head spindle; therefore if the change wheels are of equal diameter, the work will make a complete turn in 10 in., and the spiral have a lead of 10 in.

The table screw-gear and the first gear on the stud are drivers, and the gear on the worm and the second gear on the stud are driven wheels.

Expressing the ratios as fractions—

$$\frac{\text{Driven gear}}{\text{Driving gear}} = \frac{\text{Lead of required spiral}}{\text{Lead of machine}}.$$

And as the lead of the machine is 10 in., and head double geared—

$$\frac{\text{Product of driven gear}}{\text{Product of driving gear}} = \frac{\text{Lead of required spiral}}{10}.$$

RULE.—Ten times the product of the driven wheels divided by the product of the drivers = the lead of the resulting spiral in inches to one turn.

A table is generally supplied with all milling machines, from which the gear wheels can be obtained for all pitches that are most likely to be required. From this table the spiral or helix angle can also be obtained, the size of the angle of the spiral depending upon the lead of the spiral, and the diameter of the work to be milled.

The greater the lead of the spiral the smaller the angle, and the larger the diameter of the work the greater the spiral angle.

To obtain the necessary number of grooves or teeth in the work, the index head is used, as for ordinary indexing.

Table of Change Gears, Spirals, and Angles

To find the angle of spiral, divide the circumference by the pitch or lead, and the quotient will be the tangent of the angle. Then find the angle in a table of tangents.

Gear on Worm.	First Gear on Stud.	Second Gear on Stud.	Gear on Screw.	Pitch in Inches to One Turn.	Diameter of the Blank or Spiral to be Cut.						
					⅛ in.	¼ in.	⅜ in.	½ in.	⅝ in.	¾ in.	⅞ in.
					Deg.	Deg.	Deg.	Deg.	Deg.	Deg.	Deg.
24	86	24	100	·67	30¼	...	...	...	...	...	...
24	86	28	100	·78	26	44½	...	..	...	...	...
24	86	32	100	·89	23½	41	...	...	...	...	...
24	86	40	100	1·12	19	34½	...	...	...	...	...
24	86	48	100	1·34	16	30¼	41½	...	...	...	...
24	64	28	72	1·46	14¾	28	38½	...	...	...	...
24	86	56	100	1·56	13¾	26½	37	...	...	...	...
24	64	32	72	1·67	12¾	25	34¾	43¼	...	...	...
32	64	28	72	1·94	11¼	21¾	31	39	45	...	...
24	64	40	72	2·08	10¼	20½	29½	37	43¼	...	...
32	56	28	72	2·22	9¾	19¼	27½	35	41¼	...	...
24	64	48	72	2·50	8¾	17	25	32	38	43¼	...
40	56	28	72	2·78	8	15½	23	29½	35¼	40½	44¾
24	64	56	72	2·92	7½	15	21¾	28¼	34	39	43¼
					Angle for setting the saddle.						

Bevel Gears

Bevel gears are used to connect shafts whose axes would meet if they were extended. They are virtually cones, the diameters of the large ends being designated pitch diameters, and the pitch being the distance between the centre of one tooth and the centre of the next, on the large diameter. Fig. 94 shows a possible gear arrangement of bevel wheels, and Fig. 95 an impossible one. Fig. 96 shows a 2 to 1 arrangement in section.

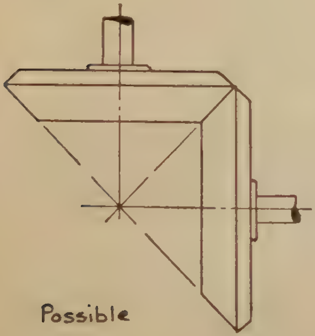


FIG. 94.—Bevel Gear.

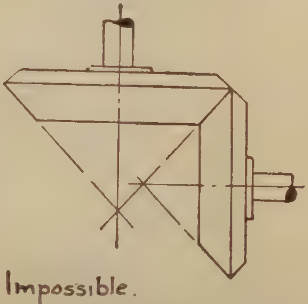


FIG. 95.—Bevel Gear.

Formula for Cutting Bevel Gears

Fig. 97.—Measure the back cone radius *ab* for the gear, or *bc* for the pinion. This is equal to the radius of a spur gear, the number of teeth in which would determine the cutter to use. Hence, twice *ab* times the diametral pitch equals the number of teeth for which the cutter should be selected for the gear. The list of cutters is shown on page 136.

Example.—Let the back cone radius *ab* be 4 in., and the diametral pitch be 8. Twice $4 = 8$ and $8 \times 8 = 64$, from which it can be seen that the cutter must be of shape No. 2, as 64 is between 55 and 134, the range covered by No. 2 cutter. See table on page 136.

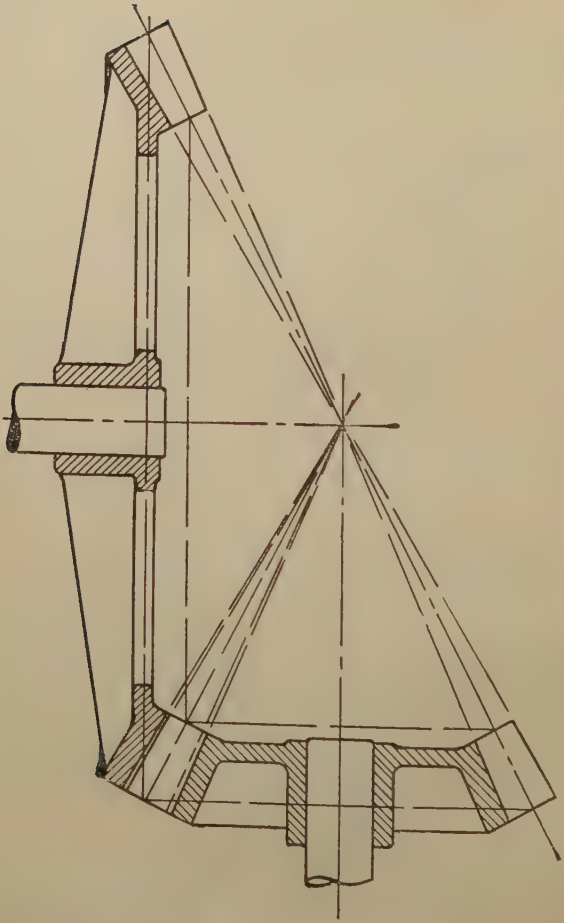


FIG. 96.—Bevel Gear in Section.

The number of teeth for which the cutter should be selected can also be found by the following formula :—

$$\text{Tan } a = \frac{Na}{Nb}.$$

$$\text{Number of teeth to select cutter for gear} = \frac{Na}{\text{Cos } a}.$$

$$\text{,, \quad ,, \quad ,, \quad ,, \quad pinion} = \frac{Nb}{\text{Sin } a}.$$

Na = Number of teeth in gear.
Nb = ,, ,, pinion.
a = Centre angle of gear.

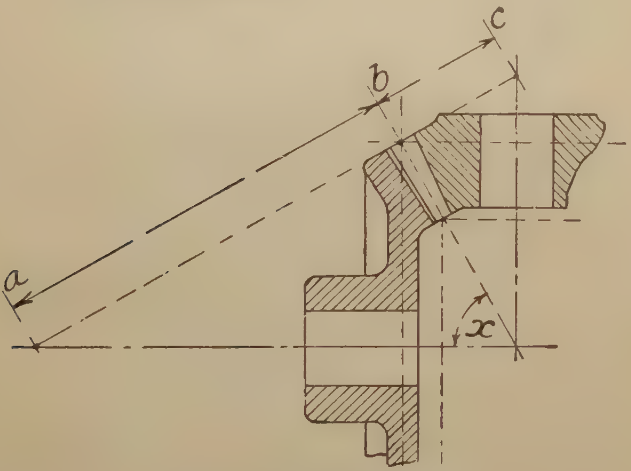


FIG. 97.—Bevel Gear Formula.

The teeth of bevel wheels can only be cut accurately in a bevel gear-shaping machine. The method of cutting in the milling machine does not always give the desired result, owing to the changing of the position of the cutter and the blank. To obtain the correct thickness of tooth at both ends, the cutter has to be suitable for cutting the smallest end of the tooth, and must be narrow enough to pass between the small end of two teeth. Therefore, the larger spaces must be cut by moving either the blank or cutter sideways, and a second cut taken.

CHAPTER VIII

SOLDERING AND BRAZING

Soldering may be termed the uniting of two pieces of the same or of different metals by means of a fusible alloy below red heat. It is the most simple means of joining metals, and also makes the weakest joint.

When soldering it is usual to have some form of soldering iron. These soldering bits are made from copper into various shapes to suit the particular work for which they are required.

A Flux is also necessary to prevent the oxidation of the metal surfaces, to facilitate the melting and flowing of the solder, and to clean the metals.

The following fluxes are used :—

Zinc chloride.
Resin.
Resin and oil.
Dilute hydrochloric acid, 10 per cent.
Tallow.

Zinc chloride can be used for general soldering except on zinc and lead.

Resin and resin and oil are chiefly used for soldering copper and electrical fittings.

A 10 per cent. solution of hydrochloric acid will be found the best flux for soldering zinc, and tallow the best for soldering lead.

Solders.—Soft solder is an alloy of lead and tin with the addition of bismuth.

The following table gives the melting point of various compositions :—

SOFT SOLDERS

Lead.	Tin.	Bismuth.	Melting Point, Fahr.
			Degrees.
4	4	1	320
3	3	1	310
2	2	1	290
1	1	1	255
1	1	2	200
8	4	15	150

When soldering, the joints of metals should be first thoroughly cleaned, and then a small amount of the flux applied to the parts to be joined. A little solder can then be picked up with the soldering bit and rubbed on the parts, which can be placed together. After this the soldering iron is rubbed along the seam, and it should have sufficient heat to make the solder run together and unite.

Tinning.—It is sometimes necessary to tin work. This can be done by first thoroughly cleaning the part, dipping it in a flux, and then putting it in a bath of molten solder. In a few seconds the whole surface will take a thin coating of solder, and it can then be lifted out and drained.

Sweating.—When such pieces of work as bearings or boxes, which are used in two halves, are required to be bored or machined, it is usual to first join them together by a process known as sweating.

The surfaces to be united are first machined or filed perfectly flat and true; the whole pieces are then heated, treated with a flux, and tinned or coated with solder. The parts are then joined together, heated again until the solder melts, and then pressed together until cold.

Aluminium.—Soldering aluminium is often unsatisfactory, because the aluminium, having a great heat conductivity, removes the heat from the solder. Before attempting to solder, the aluminium should be first thoroughly heated, and kept at a good temperature by means of a blow-pipe. If a soldering iron is to be used, it should be made from pure nickel, the copper of an ordinary soldering bit causing discolouring of the aluminium. For a flux the following can be used, 80 per cent. of stearic acid, 10 per cent. zinc chloride, and 10 per cent. tin chloride. For solder, a composition composed of 80 per cent. tin and 20 per cent. zinc.

Brazing or hard soldering is the uniting of metals by means of a fusible alloy, above red heat.

This is accomplished by placing between two prepared surfaces a piece of hard solder or spelter, and bringing it to a state of fusion.

A brazed joint gives a good, strong, substantial job.

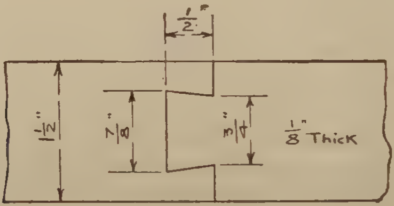
Spelter is an alloy of copper and zinc, and may be in the following proportions:—

HARD SOLDERS

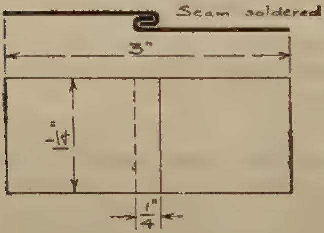
Copper.	Zinc.	Silver.
5	3	2
3	2	...
1	1	...
2	1	...

The last two are generally used, the melting point of the former being about 550° F. and the latter 700° F. By the addition of bismuth or mercury the melting point can be lowered considerably.

The flux used in brazing is powdered borax. For heating the metal a gas blow-pipe is perhaps the best method, but for large work a clear charcoal fire can be used. The parts to be joined are first heated to a cherry red, and a small amount of the flux is applied. When this runs, the spelter, which is generally in the form of soft brass filings or granulated copper and zinc, is put on with an iron spoon. The heat is then increased until the spelter melts and unites the parts.



Brazed joint.



Lap joint in sheet copper.

FIG. 97A.—Soldering and Brazing.

Fig. 97A illustrates a method of joining metal by brazing or soldering. In the brazed joint the pieces of metal are first dovetailed, not necessarily a good fit, and the top of the edges slightly chamfered to allow the spelter to run into the joints quite freely. To braze the pieces together, apply sufficient heat by means of a gas blow-pipe or a charcoal fire, to make the parts red hot. Apply a little borax and spelter, and then heat the parts sufficient to melt the spelter and allow it to run in the joints. When cool, file away any excess of metal.

In the lap joint of sheet copper the edges of the plates are first lapped over as shown, and then soldered on each side.

CHAPTER IX

PRECISION GRINDING AND LAPPING

THE chief advantages of grinding lie in the fact that it is the most rapid method of obtaining the degree of accuracy which is required in such a large proportion of modern engineering work. The process of grinding was for many years regarded as a means of sharpening tools, and the emery wheel was considered a superior kind of grindstone.

A lathe adapted specially for grinding cylindrical work, which had previously been hardened, was the initial step towards a more general use of grinding as we have it to-day.

Since the introduction of a proper water supply for dissipating the heat generated by cutter or emery wheels, the operation of grinding has obtained greatly increasing recognition. The constant improvements that are being made, both with grinding wheels and the machines on which they are used, have increased the efficiency of this method of producing accurate work.

It is now possible for certain classes of work to be finished from the solid bar, more cheaply, and to a greater degree of accuracy, than by any process of turning or filing. But generally it is more economical to first rough turn the work, leaving the finishing to be done in the grinder.

The advantages of grinding also occur where keyways have to be cut in shafts. This, in the ordinary way, would be done by machine after the shaft was turned, and consequently it might bend the shaft, so slight perhaps that it would pass unnoticed. By the grinding method the shaft could be rough turned, the keyway cut, and then ground accurately to size.

Emery Wheels.—Emery and corundum are the substances chiefly used as abrasive materials in the manufacture of grinding wheels. Rock emery stone is found in various parts of the world, and is an inferior form of corundum, and often contains a large proportion of iron. Corundum is produced from sawdust, salt, sand, and coke, these ingredients being converted into a crystal by means of an electric furnace. The rock emery stone is crushed and sieved to various degrees of fineness, and then compressed with a glutinous substance such as shellac or rubber. Wheels made by this process are known as composition wheels, and are very useful for form shapes.

The vitrified wheel perhaps gives a more ideal grinding wheel; the required grade of powdered corundum or emery is mixed with cement, or clay, or other substance, and baked by means of steam. By certain changes in the bond ensuing from the heat, it takes a glassy or vitrified form with some abrasive merit; it also contracts, and leaves the wheel porous, so that the grit projects slightly, but is held sufficiently firm to keep them in position until entirely worn away. This tenacity is termed the grade of the wheel, and is the result of the nature and amount of cement used in the making of the wheel.

Wheels are graded very soft, soft, moderately soft, medium, moderately hard, hard, and very hard.

The size of grit particles is generally denoted by a number, which corresponds with the number of squares per inch in the sieve through which the grit has passed. It is therefore possible to have wheels of the same hardness or bond and different grit numbers, or wheels with the same grit numbers and a different degree of bond.

Choice of Wheels.—For general purposes a wheel of coarse grit is to be preferred, and it can be taken that the harder the material to be ground, the softer the bond, and the finer the grit.

Large wheels are more economical than small ones, but the following considerations must be taken into account: 1. The hardness of the work. 2. Speed of the wheel. 3. Degree of finish. 4. Speed of the work. The most effective speed for grinding wheels is between 5,000 and 6,000 ft. per minute, and the general speed given to cylindrical work being about 25 ft. per minute for roughing, and slightly slower for finishing. The following table shows the number of revolutions required for specified rates of periphery speed:—

Diameter of Wheel.	For a Surface Speed of 5,000 ft.	For a Surface Speed of 6,000 ft.
In.	Revs. per Min.	Revs. per Min.
1	19098·54	22918·25
2	9549·27	11459·12
3	6366·18	7639·41
4	4774·63	5729·56
5	3819·70	4583·65
6	3183·09	3819·70
7	2728·36	3274·03
8	2387·31	2864·78
10	1909·85	2291·83
12	1591·54	1909·85
14	1364·18	1637·02
16	1193·66	1432·39
18	1061·03	1273·24
20	954·92	1145·91
22	868·11	1041·74
24	795·77	954·93
30	636·61	763·94
36	530·51	636·62

The following is an extract from an article written by an expert on grinding: "The amount of work produced by grinding has increased with the increase of water, and now it is known that soda water increases the product from any given wheel; later the introduction of oil into the soda water has still further increased the productiveness of wheels, and made the work of the operator pleasanter, on account of the greater neatness. The so-called drilling compound has been used and found to be excellent when sufficient soda is added to prevent rust."

All really good wheels will grind in either soda water, soapy water, or oil. It is only necessary that they should be graded rightly. The popular idea that oil must not be allowed to get near any grinding wheel is erroneous. It would be bad to soak some wheels in oil, or to allow oil to penetrate to any extent; but no really good wheel to-day can be injured by flowing liquid oil on to the work or wheel while the wheel is revolving at a sufficient speed to accomplish its work, and some wheels may be soaked in oil indefinitely without the slightest injury.

Another erroneous impression, not, however, so common, is that emery adheres to ground surfaces, causing cutting of bearings when used. It would seem clear to reason that, should emery adhere to the steel, there would be no grinding, but instead the wheel would be torn away. The fact is that neither the microscope nor chemical laboratory reveals an atom of carbon in any form adhering to the steel.

There still remain a few who suppose that copper, babbit metal, lead, and rubber cannot be ground with emery and corundum wheels because the metal adheres to the cutting wheel; when the fact is, there is no substance that cannot be ground successfully with a wheel suitably constructed for each case.

Hand Grinding.—The operation of precision grinding would be carried out entirely by a grinding machine automatically, and hand grinding would be defined as operations performed by means of the work being pressed up against a revolving wheel. In all shops emery wheels have taken the place of grindstones for sharpening tools; and the disc grinder for removing small areas of metal.

Machine Grinding.—The term machine grinding would be applied to the production of finished surfaces, by means of an abrasive material, in automatic or partly automatic machines. Machine grinding can be divided into the following classes: surface grinding, tool and cutter grinding, cylindrical and cutter grinding, disc grinding, and internal grinding. In all the classes of grinding the degree of accuracy obtained depends far more on the accuracy of the machine than on the skill of the operator.

Dry Grinding.—Dry grinders are chiefly used in the general shop for touching up small tools or pieces of work. The usual form consists of a base supporting two bearings, in which revolve a spindle constructed to carry a pulley-wheel for driving, the ends being turned, tapered, and screwed to take the emery wheels. The wheels are held in position by means of a flange and two lock-nuts.

Large dry floor grinders which are built to withstand rough handling and heavy use are often supplied to a foundry, and are specially useful for fettling castings.

Wet Grinders.—Grinders for hand work are much to be preferred. The water can be supplied by several different methods, and in some cases it is obtained in the following manner:—

The inside of the body of the machine forms a tank into which can be lowered flooding blocks. The blocks being lifted and lowered as desired, can be made to force the water to the front of the wheel. The water can then be regulated from a fine spray to a flood.

A tool rest is fitted which can be adjusted horizontally to allow for the wear of the wheel, and on some type of

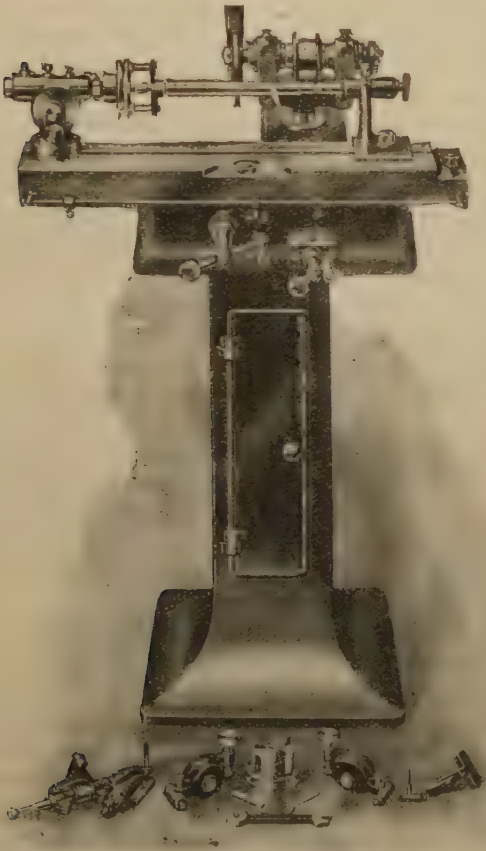


FIG. 97B.—Universal Tool and Cutter Grinder.

machines it is constructed to be moved vertically or swivelled as required.

Universal Tool and Cutter Grinder.—Fig. 97B illustrates a modern type of universal tool and cutter grinder. This machine will grind accurately and quickly, within the limits of 7 in. and 13 in. The wheel headstock swivels, so that either cup or face wheels may be used. The spindle is provided with dust-proof ball bearings. An adjustable wheel guard is fitted, enabling the grinding wheel to be changed without removing the guard. The table can be swivelled for grinding taper and conical work. Stops are fitted to a rod on the front of the table for limiting the movement in either direction. The universal headstock swivels horizontally and vertically, and is graduated. The spindle is bored No. 2 Morse taper, and the nose is turned No. 3 Morse taper, so that a chuck, driver plate, or face plate may be fitted. The driver plate is fitted with a taper bronze bush, so that work may be ground on dead centres, and the spindle may be locked or allowed to revolve as desired.

Two adjustable headstocks are fitted to facilitate the grinding of hobs, taps, reamers, gear cutters, etc., where it is necessary that the work should pass under the wheel. The countershaft for this machine is entirely self-contained, and a double belt shifting arrangement enables the work to be stopped independently of the grinding wheel.

The Surface Grinder.—This type of machine is used for such work as finishing piston rings, discs, thrust collars, saws, milling cutters, and similar work.

The crosshead which carries the wheel slide is usually adjustable, so that surfaces may be finished either perfectly flat, convex, or concave as may be desired.

When fitted with a magnetic chuck this type of machine will grind the thinnest possible work.

Universal Grinding. — The general design of a universal grinding machine is similar to the universal miller, and within the capacity of the machine all classes of grinding can be accomplished.

The wheel, which is revolved by means of an overhead pulley, is moved along the rotating work transversely, and also fed towards the work.

Speeds and Feeds

Before grinding is commenced it is necessary to calculate the following :—

1. The correct speed for the emery wheel.
2. The correct speed for the work.
3. The right amount of travel for the wheel.

1. Is determined by the character of the wheel being used, and can be left for the makers to decide. 2. The number of revolutions given to the work depends on the diameter, and should give a surface speed of about 25 ft. per minute. 3. The correct rate of traverse must be determined by the character and size of the work, but generally it is considerably faster for light or finishing cuts than for roughing.

Disc Grinding.—Disc grinders are being used to a large extent in general workshops, and while not giving a perfectly true surface, they can be used for rapidly removing small amounts of metal. The machine is similar to the general type of dry grinder, and is fitted with steel discs turned perfectly true.

To the surface of the discs circular sheets of emery of various grades can be cemented, and by varying the grade of emery cloth the work can be roughed or finished as desired. These machines are generally fitted with various adjustments in order that different classes of work may be treated in a quick and economical manner.

Chattering.—Chattering in work is generally caused by lack of rigidity in the machines, want of truth in the running of the emery wheel, or rotating the work too rapidly.

When long slender work is being ground it should be supported by means of a steady rest, and if the wheel is not running perfectly true, it should be first turned up by taking a cut along in the lathe.

Truing Wheels.—The best method of truing wheels is by means of a diamond, which is the only proper tool. The diamond is fixed in a suitable holder, and held in a rigid position in the machine; the wheel is rotated in the same plane and at the same speed as when working. Water should be used during this operation, and a large number of light cuts are to be preferred to a few heavy ones.

When turning wheels in form shape, it is necessary to move the tool by hand so as to produce to form required.

For dressing wheels used on rough work a dressing cutter can be used. This is moved along the face of the wheel by hand.

Laps and Lapping

Lapping is a method of accurately finishing work by an abrasive process. A surface which has been finished in the grinding machine may not have a good enough surface for some classes of work. Standard measuring gauges, and in some cases journals of shafts, are lapped after being ground.

Laps may be made from cast iron, copper, and other metals. Copper will hold the abrasive more easily than cast iron, but it sooner loses its shape.

The best material for laps is good, close-grained, well-annealed cast iron.

Laps for holes are frequently made in halves in the form of bushes fitted to a tapered arbor.

The Abrasive used for lapping is emery powder or ground glass, and during use a good supply of oil is necessary. A small amount of the abrasive material is smeared on the surface of the lap, mixed with a little oil.

CHAPTER X

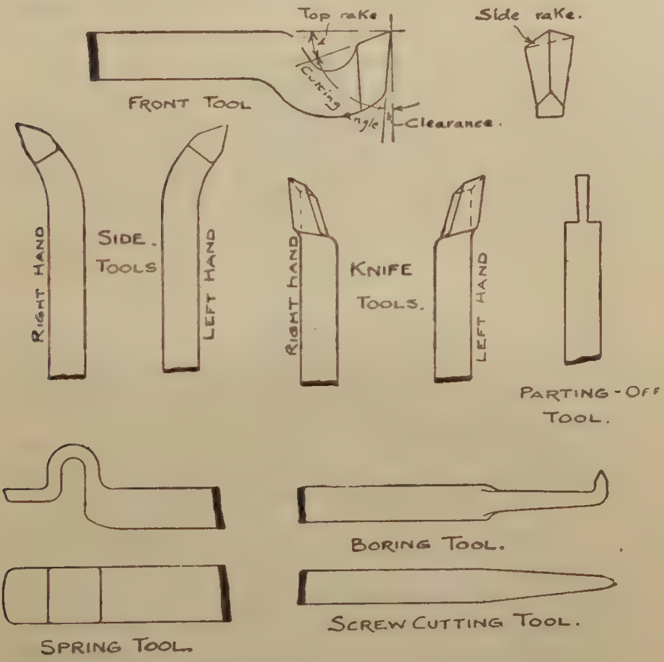
LATHE TOOLS AND THEIR USE

SUCCESSFUL and accurate turning can only be accomplished by the use of lathe tools of correct shape, ground to the most suitable angles for the metal being cut, and used in a correct manner. Cutting tools differ in shape according to the work about to be performed. This shape is governed to some extent by the nature of the metal to be cut, but more often it is a question of cutting angles, front and side rake, and clearance.

A set of lathe tools for ordinary work consists of front tools, right and left hand side tools, right and left hand knife tools, parting tools, boring tools, and screw-cutting tools for Whitworth and square threads. In some of these tools it is usual to have one each for roughing and finishing both hard and soft metals.

Cutting Angle.—A tool ground to the wrong angle either digs in or rubs its cutting edge away. To determine the correct cutting angle it is necessary to bear in mind that, while it is desirable to have a keen tool, it is also necessary to have sufficient metal to support the cutting edge. The softer the metal being cut the smaller the cutting angle required. With a good class of tool steel the cutting angle for turning wrought iron would vary between 40° and 65°; for cast iron, between 65° and 80°; for steel, between 60° and 80°; and for brass, between 85° and 90°.

Front and Side Rake.—The front and side rake of a lathe tool is also governed by the hardness and toughness of the metal to be turned. If a fibrous metal like wrought iron is being cut, by giving the tool the



LATHE TOOLS.

MATERIAL.	CUTTING ANGLE	CLEARANCE.
WROT. IRON.	65°	5°
HARD STEEL.	75°	3°
CAST IRON.	70°	10°
BRASS.	85°	5°
CHILLED IRON	80°	3°

correct amount of front and side rake the turning will come off several feet in length. To attempt to turn brass or cast steel with a tool having much rake would be disastrous, the tendency of brass being to draw the tool in and break off the point, and the cast steel would be much too hard, and the cutting edge would be soon burnt away. Side rake lessens the power required to move the tool, and enables the cutting edge to more easily penetrate the metal. The top rake given to a tool for turning wrought iron would vary between 20° and 30°; for cast iron and steel, 10° to 25°; and for brass, 0° to 10°.

Clearance

The object of clearance being simply to allow the tool to cut without rubbing, an excessive amount weakens the point, and therefore it should be as small as possible, from 3° to 8° being usual, the former for cast iron or steel, the latter for brass.

Height of the Tool

In turning any description of work, or any particular metal in an ordinary lathe, the correct position of the tool is for the cutting edge to be level with the point of the lathe centre. The fact of the tool being a little high or low when turning a piece of work of large diameter is not of great importance, but when turning very small or taper work it is of the utmost importance, and unless quite correct, will give bad results.

If it should be necessary to use packing to raise a tool in the tool holders, care should be taken that it is placed the full length, and not packed under the back or front of the tool. It requires little thought to show that packing the tool out of level or having it placed with the cutting edge above or below the lathe centre, will alter both the cutting angle and the clearance, and would give the tool the tendency to either grind on the work or scrape on the cutting edge, and soon become useless as a cutting tool.

Holding the Tool

The support of the tool in the tool rest depends to some extent on the nature of the job, but in all cases, for roughing or heavy work, the closer the cutting edge is to the holding down plates the better, the tendency of having a firm tool being to stop chattering, and to allow of the cutting angle to be made keener.

Tool Holders

Many excellent tool holders are on the market at the present time, and for many varieties of work they are particularly useful. Their advantages are chiefly: The facility with which a tool can be removed and replaced, the ease with which the height of the tool can be adjusted, and the low initial cost of metal for tools, owing to the small amount required.

The introduction of high-speed self-hardening steels has made a remarkable difference in the use of lathe tools, particularly with regard to speeds and feeds, and it is now possible to run at speeds, and take advantage of the economy of heavy cuts, unthought of a few years ago.

Cutting Speeds

The cutting speed of any metal depends upon its hardness, and it is very difficult to lay down any definite rule with regard to speeds and feeds, so much depending upon the quality of the tool steel and the size and rigidity of the lathe.

The feeds also depend upon the power of the lathe, and whether a roughing or finishing cut is being taken.

The following speeds can be taken as general workshop practice :—

Metal.	Cutting Speeds.
Wrought iron	35 to 65 feet per minute.
Mild steel	25 ,, 70 ,, ,,
Hard steel	20 ,, 35 ,, ,,
Brass	40 ,, 150 ,, ,,
Cast iron	30 ,, 50 ,, ,,

When taking heavy cuts on hard metals, it is better to decrease the speed and increase the feed.

When taking finishing cuts on wrought iron, increase the speed and also the feed; when on cast iron, increase the speed but decrease the feed; when on hard steel, retain the speed and increase the feed.

Cooling of Tools

The heating up of lathe tools, and the consequent grinding away of cutting edges, can be reduced to a great extent by the use of some cooling mixture such as soft soap and soda water. This mixture will also prevent the distortion of the work, which might be brought about by the expansion of the metal.

On lathes taking long and heavy cuts, it is usual to fix some form of pump that will deliver a steady and continuous flow of cooling liquid on the cutting edge of the tool.

In using a cooling mixture as a lubricant on small work, the simplest and best method of applying it is by means of a pot and brush.

For finishing steel and wrought iron a high and accurate finish can only be obtained by using a plentiful supply of soapy water.

It has been estimated that the cutting speed of high-speed tools can be increased about 40 per cent. by using a continuous stream of cooling water.

TABLE OF CUTTING SPEEDS

Surface Speeds of Various Diameters and Revolutions

Feet per Min.	10	12	14	16	18	20	25	27½	30	35
Diam. Inch.	Turns per Minute.									
¼	153	183	214	244	275	306	382	420	458	535
⅜	102	122	143	163	183	204	255	280	306	357
½	76	92	107	122	137	153	191	210	228	267
⅝	61	73	86	98	110	122	153	168	183	214
¾	51	61	71	81	92	102	127	140	153	178
⅞	44	52	61	70	79	87	109	120	131	153
1	38	46	53	61	69	76	95	105	114	134
1⅛	34	41	47	54	61	68	85	93	102	119
1¼	31	37	43	49	55	61	76	84	91	107
1⅜	28	33	39	44	50	55	69	76	83	97
1½	25	30	36	41	46	51	64	70	76	89
1¾	22	26	30	35	39	44	55	60	65	76
2	19	23	27	30	34	38	48	52	57	67
2¼	17	20	24	27	30	34	42	47	51	59
2½	15·27	18·3	21	24	27	31	38	42	46	53
2¾	13·8	16·6	19·4	22	25	28	35	38	42	49
3	12·7	15·2	17·8	20	23	25	32	35	38	44
3¼	11·7	14·1	16·4	18·8	21	23	29	32	35	41
3½	10·9	13·1	15·3	17·4	19·6	22	27	30	33	38
3¾	10·18	12·2	14·2	16·3	18·3	20·3	25	28	30	36
4	9·5	11·4	13·4	15·2	17·2	19·1	24	26	29	33
4½	8·5	10·2	11·9	13·6	15·3	17·0	21	23	25	30
5	7·6	9·2	10·7	12·2	13·7	15·27	19·1	21	23	27
5½	6·9	8·3	9·7	11·1	12·5	13·9	17·4	19·1	20·8	24
6	6·4	7·6	8·9	10·2	11·5	12·7	15·9	17·5	19·1	22
6½	5·85	7·0	8·2	9·4	10·6	11·7	14·7	16·1	17·6	20·5
7	5·45	6·5	7·6	8·7	9·8	10·9	13·6	15·0	16·4	19·1
7½	5·1	6·1	7·1	8·1	9·2	10·2	12·7	14·0	15·3	17·8
8	4·75	5·7	6·7	7·6	8·6	9·5	11·9	13·1	14·3	16·7
8½	4·5	5·4	6·3	7·2	8·1	9·0	11·2	12·3	13·5	15·7
9	4·25	5·1	5·9	6·8	7·6	8·5	10·6	11·7	12·7	14·9
9½	4·0	4·8	5·6	6·4	7·2	8·0	10·0	11·0	12·0	14·0
10	3·8	4·6	5·3	6·1	6·9	7·6	9·5	10·5	11·5	13·36
11	3·45	4·16	4·8	5·5	6·27	6·9	8·7	9·5	10·4	12·2
12	3·2	3·8	4·4	5·1	5·7	6·4	7·9	8·7	9·5	11·16
13	2·9	3·5	4·1	4·7	5·3	5·9	7·3	8·1	8·8	10·3
14	2·7	3·3	3·8	4·4	4·9	5·4	6·8	7·5	8·2	9·5
15	2·55	3·0	3·6	4·0	4·6	5·1	6·4	7·0	7·6	8 9
16	2·37	2·9	3·3	3·8	4·3	4·8	6·0	6·6	7·16	8·3
17	2·25	2·7	3·1	3·6	4·0	4·5	5·6	6·2	6·7	7·9
18	2·12	2 5	2·97	3·4	3·8	4·2	5·3	5·8	6·3	7·4
19	2·0	2·4	2·8	3·2	3·6	4·0	5·0	5·5	6·0	7·0
20	1·9	2·3	2·67	3·0	3·4	3·8	4·8	5·2	5·7	6·68
21	1·8	2·18	2·55	2·9	3·3	3·6	4·5	5·0	5·4	6·3
22	1·72	2·08	2·4	2·8	3·1	3·4	4·3	4·7	5·2	6·1
23	1·66	2·0	2·3	2·6	3·0	3·3	4·1	4·5	5·0	5·8
24	1·59	1·9	2·2	2·5	2·8	3·2	4·0	4·3	4·7	5·5

TABLE OF CUTTING SPEEDS—*Continued*

Surface Speeds of Various Diameters and Revolutions

Feet per Min.	40	45	50	60	70	80	90	100	110	120
Diam. Inch.	Turns per Minute.									
¼	611	688	764	917	1070	1222	1375	1528	1681	1833
⅜	408	458	509	611	713	815	916	1018	1120	1222
½	306	344	382	458	535	611	688	764	840	916
⅝	244	275	306	367	425	489	550	611	672	733
¾	204	229	254	306	357	407	458	509	560	611
⅞	175	196	218	262	306	349	393	436	480	523
1	153	172	191	229	267	306	344	382	420	458
1⅛	136	153	170	204	238	272	305	339	374	407
1¼	122	138	153	183	214	244	275	305	336	366
1⅜	111	125	139	166	194	222	249	277	305	332
1½	102	114	127	153	178	204	229	254	280	305
1¾	87	98	109	131	153	175	196	218	240	262
2	76	86	95	114	133	153	172	191	210	229
2¼	68	76	85	102	119	136	153	170	187	204
2½	61	69	76	92	107	122	137	153	168	183
2¾	55	62	69	83	97	111	125	139	152	166
3	51	57	64	76	89	102	115	127	140	153
3¼	47	53	59	70	82	94	106	117	129	141
3½	44	49	54	65	76	87	98	109	120	131
3¾	41	46	51	61	71	81	92	102	112	122
4	38	43	48	57	67	76	86	95	105	114
4½	34	38	42	51	59	68	76	85	93	102
5	30	34	38	46	53	61	69	76	84	92
5½	28	31	35	42	49	55	62	69	76	83
6	25	28	32	38	44	51	57	64	70	76
6½	23	26	29	35	41	47	53	59	65	70
7	22	25	27	33	38	44	49	54	60	65
7½	20·4	23	25	31	36	41	46	51	56	61
8	19·1	21	24	29	33	38	43	48	52	57
8½	18	20·2	22	27	31	36	40	45	49	54
9	17·0	19·1	21·2	25	30	34	38	42	47	51
9½	16·1	18·1	20·1	24	28	32	36	40	44	48
10	15·27	17·2	19·1	23	27	31	34	38	42	46
11	13·9	15·6	17·4	20·8	24	28	31	35	38	41
12	12·7	14·3	15·9	19·1	22	25	29	32	35	38
13	11·8	13·2	14·7	17·6	20·6	23	26	29	32	35
14	10·9	12·3	13·6	16·4	19·1	22	24	27	30	33
15	10·2	11·4	12·7	15·3	17·8	20·4	23	25	28	30
16	9·5	10·7	11·9	14·3	16·7	19·1	21·4	24	26	29
17	9·0	10·1	11·2	13·5	15·7	18·0	20·2	22	25	27
18	8·5	9·5	10·6	12·7	14·8	17·0	19·1	21	23	25
19	8·0	9·0	10·0	12·0	14·1	16·1	18·1	20	22	24
20	7·6	8·6	9·5	11·4	13·3	15·3	17·2	19	21	23
21	7·3	8·2	9·1	10·9	12·7	14·6	16·4	18	20	22
22	6·9	7·8	8·7	10·4	12·1	13·9	15·6	17·3	19	20·8
23	6·6	7·5	8·3	10·0	11·6	13·3	14·9	16·6	18·2	19·9
24	6·3	7·16	7·9	9·5	11·1	12·7	14·3	15·9	17·5	19·1

CHAPTER XI

TURNING

The various types of lathes are innumerable, and a very large book would be required to describe them in detail. Fig. 98 illustrates a standard type of screw-cutting lathe.

The chief dimension of any lathe is the height of its centre, or the distance from the top face of the lathe to the centre of the mandrel. The maximum diameter of the work which could be turned would be a little larger than twice the centre height, or if provided with a gap, it would be twice that amount larger. In either case the distance the saddle stands above the lathe bed reduces the diameter of the work that can be turned between the centres.

The distance between centres is a dimension often given, and is the maximum length of work that can be turned between the centres.

The following dimensions are usually given by the makers of lathes:—

1. The amount of swing over the lathe bed.
2. The amount of swing over the carriage.
3. The length of the bed.
4. The greatest distances between centres.

The characteristics of a good lathe are as follows:—

The bed should be strong enough to withstand the heaviest cutting without strain, have large broad surfaces, and be well stayed.

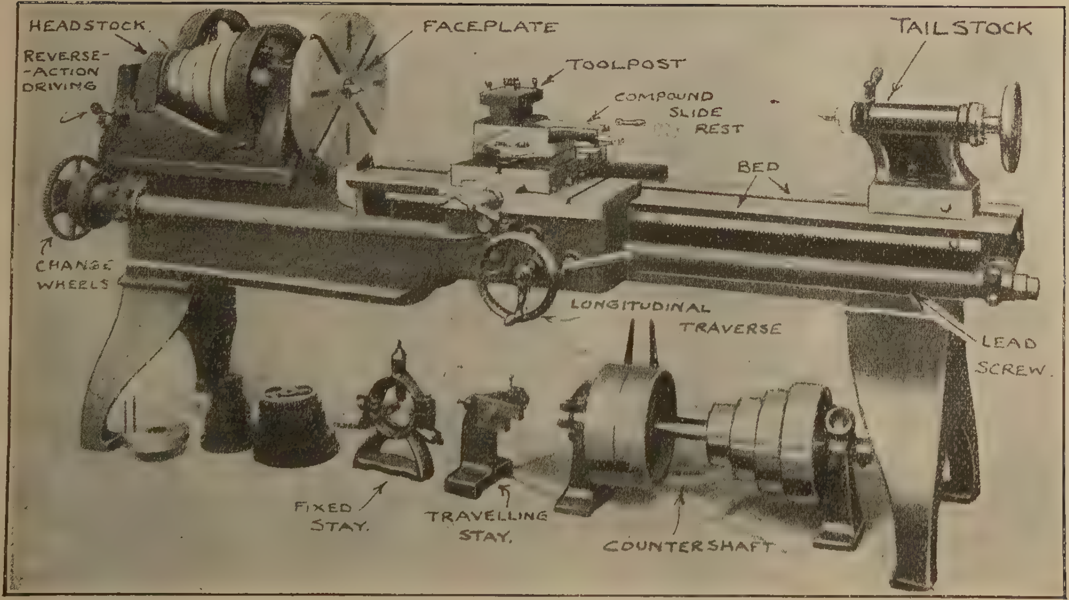


FIG. 98.—Screw-Cutting Lathe.

The mandrel or spindle should be made from high carbon steel, have large bearing surfaces, and should be hardened and ground accurately to size, and should be preferably hollow.

The countershaft or overhead gear should be provided with an efficient method of striking the driving belt on or off. Fig. 99 illustrates a form of countershaft which has proved very efficient.

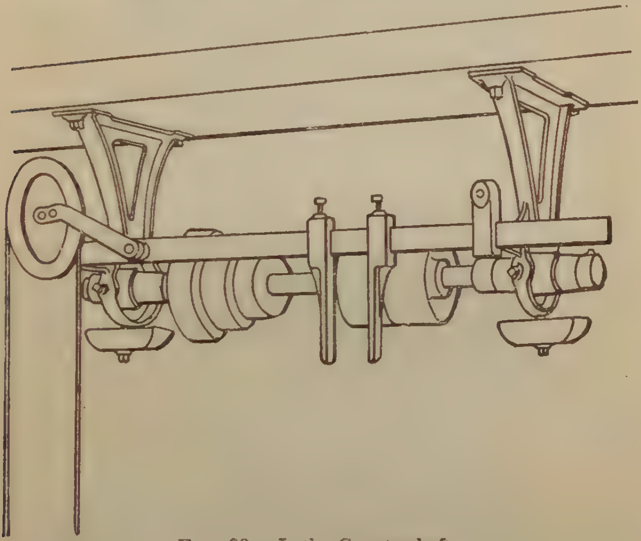


FIG. 99.—Lathe Countershaft.

The fast headstock should be fitted with large bearings, have an efficient and well designed back gear, and be provided with a cone pulley to take a wide belt.

The tailstock, or, as it is often called, the loose headstock, should be proportionately rigid to the fast headstock. NB

The spindle should have a large area and be ground to size, the casing being provided with an efficient locking gear. The screw should be left-handed, and have lock-nuts at the back of the hand wheel to take up any wear between the collar and its bearing. An arrangement should be fitted for making the side adjustments which are necessary for taper turning.

The saddle or carriage should have large bearing surfaces, and should move in the same direction as the handles when on top.

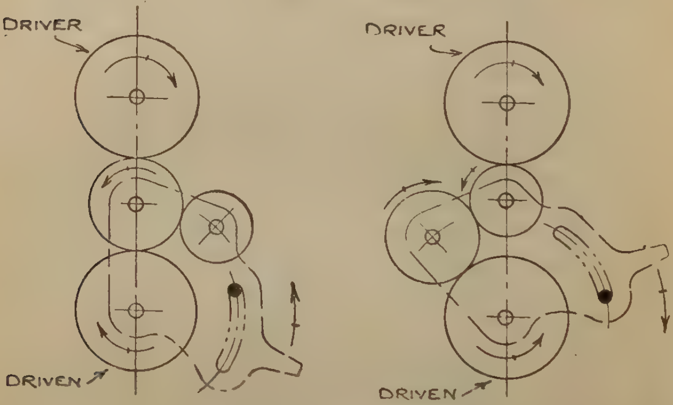


FIG. 100.—Reversing Gear.

The leading screw, being one of the most important parts of the lathe, should be accurately cut, and a simple and effective method of connecting and disconnecting it to or from the saddle should be provided.

Some form of reverse action should be fitted in order to move the saddle automatically in either direction. Fig 100 illustrates a method very frequently adopted.

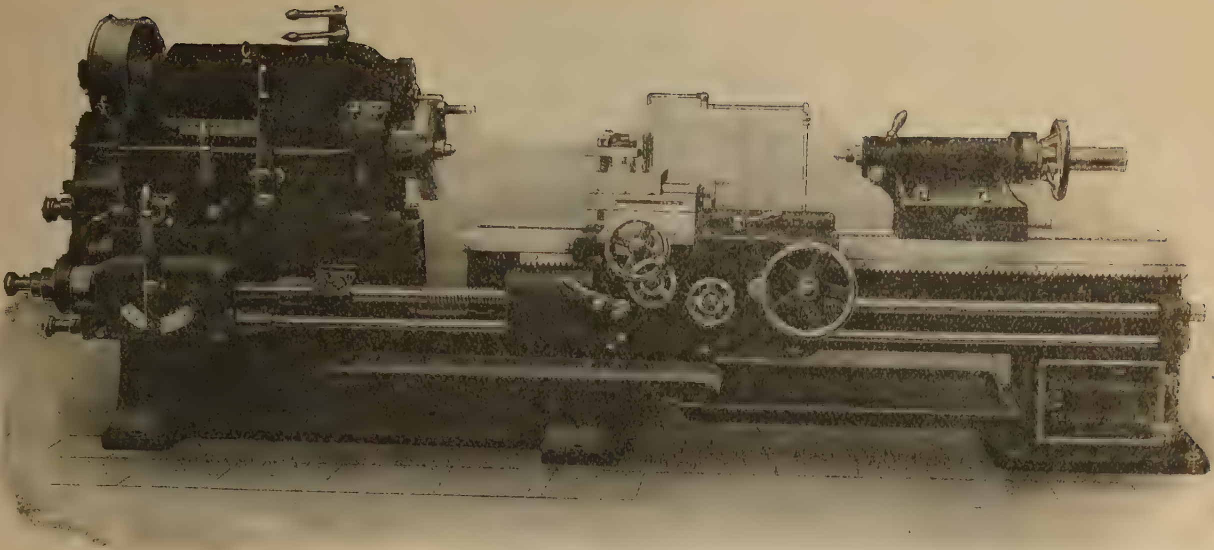


FIG. 100A.—10½-in. Centres All-geared Single Pulley Lathe.

Modern Lathes

The improvements made in recent years have been most in the direction of increased strength and power; bearings, mandrels, and headstocks have been made larger, and great advances have been made in the direction of improved speeds and feeds. Fig. 100A illustrates a modern $10\frac{1}{2}$-in. centres all-geared lathe, fitted with a single pulley drive, made by Messrs Dean, Smith, & Grace, of Keighley. The length of bed is 10 ft., and it will admit work 4 ft. in length between centres. The greatest diameter of work that can be taken over the saddle is 15 in., while in the gap it will swing 41 in., $10\frac{1}{2}$ in. wide in front of the face plate. The feeds are 8, 16, 32, or 4, 8, and 16 cuts per inch. The leading screw is $2\frac{1}{4}$ in. diameter of $\frac{1}{2}$ in. pitch. The front spindle bearing is 6 in. in diameter by $7\frac{3}{4}$ in. long, which gives ample bearing surface. The driving pulley is 16 in. diameter by 5 in. wide, with a driving speed of 480 revolutions per minute, allowing for 16 spindle speeds varying between 8.5 to 127.5 revolutions per minute.

The power is transmitted through gearing having friction and positive clutches combined. The friction clutch brings the shaft up to speed, the positive then coming in solid. These clutches are made from oil-hardened steel, and the fast running shafts from steel of high tension.

This type of lathe is easily adaptable to a constant speed motor, driving on to the lathe by means of wheels and a chain. The motor is generally secured by bolting it to a specially designed stand which is fastened to the lathe bed by a large base, thus making it practically solid with the machine. Fig. 100B shows the lathe adapted for driving by a constant speed motor.

The self-acting feeds are positive, and are reached through gear contained in the box on the front of the bed. This is shown in Fig. 100C. The gearing is practically indestructible, as the sleeve is made from a steel forging with

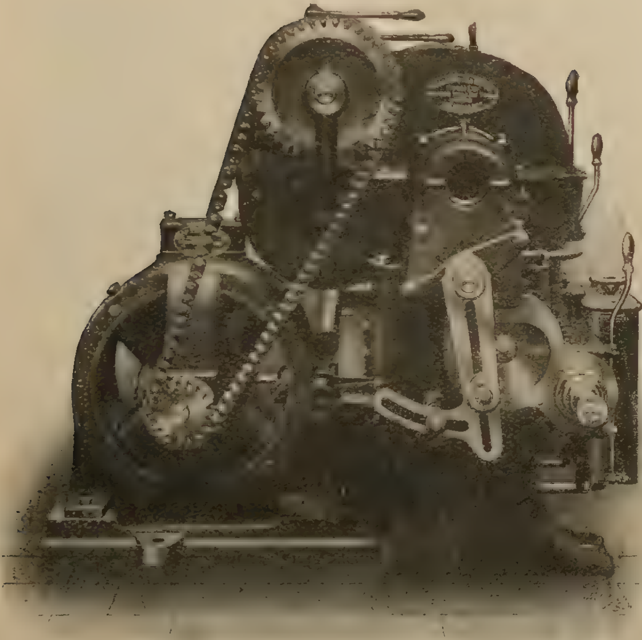


FIG. 100B.--Motor Driving Lathe Direct.

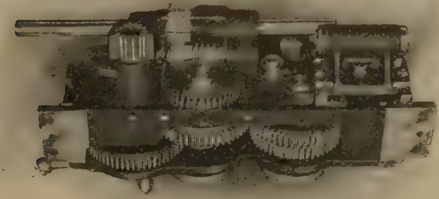


FIG. 100C.—Feed Arrangement.

teeth cut from the solid, the whole of the feed mechanism being made of steel, the parts liable to wear being case hardened.

Surfacing Feed

For the purpose of automatically surfacing work, motion is often transmitted from the lead screw by means of a worm wheel and bevel wheels. The ratio can be found by multiplying all the driving wheels, and also all the driven wheels, and then multiplying each by the pitch of the screws, either driving or driven, which transmit motion

Sliding Feed

When a lathe is not fitted with a separate shaft for giving an automatic sliding feed, the lead screw can be used instead, by simply putting on a compound train of wheels that will give a very fine thread.

The Back Gear

In order to obtain sufficient power to take deep cuts on large or heavy work, and also to decrease the speed of the lathe, the back gear is used.

The following is a description of the common type of simple back gear :—

On the lathe mandrel, one wheel is keyed called the plate wheel, the step cone pulley and pinion wheel being free to revolve if desired. The back shaft has a wheel and pinion keyed on to it, and can be drawn into gear either by an eccentric motion or by sliding.

When using the back gear, the pulley is freed from the plate wheel, and the back shaft wheels put into gear.

When running without the back gear, the back shaft wheels are taken out of gear, and the pulley is secured to the plate wheel by means of a bolt or pin.

Thus when running with the back gear the motion is transmitted from the countershaft to the cone pulley, which will run free on the lathe spindle and drive the back shaft through the medium of the pinion and wheel, this in turn driving the lathe spindle by means of the pinion and plate wheel.

The object of the back gear being to obtain a large range of speeds, and also to take heavy cuts, it is necessary to know what the reduction of the speed actually is

To take an example. On an 8-in. lathe the speed cone has four speeds, the diameter of each speed being $3\frac{5}{8}$ in., $5\frac{1}{8}$ in., $6\frac{5}{8}$ in., and $8\frac{1}{8}$ in. The countershaft pulley revolves at 100 revolutions per minute. The pinion wheels of the lathe spindle and back shaft have 16 teeth each, and the wheels themselves have 48 each. To find the various speeds—

Then, $$\frac{16 \times 16}{48 \times 48} = \frac{1}{9},$$

or the back gear will reduce the velocity of the lathe mandrel compared with the cone pulley as 1 is to 9, the cone pulley revolving nine times as fast as the lathe mandrel.

The cone pulley having four speeds, by using the back gear eight different speeds can be obtained, these being—

Speed without back gear $\frac{100 \times 8\frac{1}{8}}{3\frac{5}{8}} = 224{\cdot}1.$

,, ,, ,, $\frac{100 \times 6\frac{5}{8}}{5\frac{1}{8}} = 129{\cdot}2.$

,, ,, ,, $\frac{100 \times 5\frac{1}{8}}{6\frac{5}{8}} = 77{\cdot}3.$

,, ,, ,, $\frac{100 \times 3\frac{5}{8}}{8\frac{1}{8}} = 44{\cdot}6.$

Speed with back gear $\frac{224{\cdot}1}{9} = 24{\cdot}9.$

,, ,, ,, $\frac{129{\cdot}2}{9} = 14{\cdot}3.$

$$\text{Speed with back gear } \frac{77{\cdot}3}{9} = 8{\cdot}5.$$

$$\text{,, ,, ,, } \frac{44{\cdot}6}{9} = 4{\cdot}5.$$

The eight speeds obtained being 4.5, 8.5, 14.3, 24.9, 44.6, 77.3, 129.2, and 234.1.

Preparing Work

Preparing Work.—All work that is to be turned between lathe centres must be first properly prepared by correctly centring it. Several methods may be used to locate the centre, and it depends upon the shape and size of the work as to which is the best method to adopt. For cylindrical work it is usual to place the work in vee blocks, and find the centre by means of the scribing block or surface gauge. In other cases it is more convenient to use the dividers, or a pair of hermaphrodite calipers, the object being to obtain four small arcs an equal distance from the outside.

When the approximate centre is obtained, a mark is made with a centre punch, and the work is revolved between the centres of the lathe and tested for truth. If found to run out of truth, one or both centre marks must be drawn over in the direction required, and when running quite correct, the centres can be drilled up.

For the purpose of centring work a special drill is generally used which drills and countersinks at one operation. If an ordinary drill is used the hole must be countersunk with a drill ground to an angle of 60°. The size of the centring hole depends upon the size of the work. For small light work a hole $\frac{1}{16}$ of an inch in diameter, and countersunk 60°, would be large enough.

Driving.—To transfer the motion from the lathe spindle to the work, some form of carrier must be used, and this is driven either from a pin in the driving plate, as shown in Fig. 101, or by placing a bolt or pin in one of the holes or slots in the face plate.

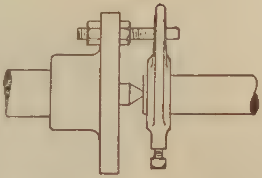


FIG. 101.—Driving Plate.

Order of Procedure.—1. Before placing any work between centres, put a little oil on the live or moving centre, and then adjust the back centre by means of the tailstock, and afterwards by means of the tailstock spindle, screwing it in or out, so that the work will revolve quite freely without being slack, and at the same time allowing sufficient room for the saddle or top slide rest to move the required amount. In adjusting the spindle, it should be kept as short as possible to obtain rigidity.

2. Next select the tool, and secure it in the tool holder with the cutting edge exactly on a level with the lathe centres.

3. Determine the speed and feed, and make the necessary adjustments to gears and belts.

4. Next try the lathe, by moving the driving pulley round one or two revolutions, and make sure everything is quite clear and secure.

5. If much metal is to be removed, start by taking a deep cut. If turning straight work, take a roughing cut all over, and then square up the ends to within $\frac{1}{32}$ of an inch of the finished length. Next file off any excess of metal at the centres, and re-countersink the hole.

6. Replace the work in the lathe, and turn with a roughing tool to within $\frac{1}{64}$ of an inch of finished size, afterwards finishing to exact dimensions with a sharp finishing tool.

Finishing Work.—When work is to have a high polish a spring tool can be used. This type of tool will be found to give an excellent finish to the work if used with a plentiful supply of cooling mixture. To obtain a fine finish on cast iron a very broad-nosed tool must be used, which can be followed with a smooth file and emery cloth. For the purpose of polishing cast iron it is usual to nail a strip of emery cloth on to a piece of wood, and use the slide rest either to hold it or to obtain a leverage.

Taper Turning.—In the absence of a special taper turning device, taper turning can be accomplished either by setting over the centres, or by altering the slide rest. The method generally used is to alter the back centre by setting over the loose headstock in such a manner as to throw the back centre out of line with the fixed centre. By adopting that means the self-acting mechanism can still be used, and the tool made to travel parallel with the lathe bed. As the amount of side adjustment is small, only slight tapers can be turned in this manner, more especially when the work is of any length.

The amount the centre has to be moved over depends upon the amount of taper required, and the length between centres. If the back centre is set over 1 in., and the work is 4 ft. long, then it will be turned 2 in. smaller at one end than at the other, and would give a cone half an inch to the foot. The objection to this form of taper turning is the unequal wear on the centre owing to the centres being out of line with each other.

The following rule applies to the set over of the loose headstock :—

$$\frac{\text{Length of work} \times \text{Taper}}{2} = \text{Distance tailstock is set out of line.}$$

Example.—Length of work, 4 ft. ; taper required, $\frac{1}{2}$ in. per foot.

Then, $$\frac{4 \times \frac{1}{2}}{2} = 1 \text{ in.}$$

Tailstock set over 1 in.

SIZE OF STANDARD TAPER PINS

Taper ¼ Inch per Foot

Number.	Largest Diameter of Pin.	Smallest Diameter of Pin.	Number.	Largest Diameter of Pin.	Smallest Diameter of Pin.
0	·156	·135	6	·341	·279
1	·172	·146	7	·409	·331
2	·193	·162	8	·492	·398
3	·219	·183	9	·591	·482
4	·250	·208	10	·706	·581
5	·289	·240			

TAPERS PER FOOT AND CORRESPONDING ANGLES

Taper per Ft.	Included Angle.		Angle with Centre Line.		Taper per Ft.	Included Angle.		Angle with Centre Line.	
Inches.	Deg.	Min.	Deg.	Min.	Inches.	Deg.	Min.	Deg.	Min.
1/8	0	36	0	18	2½	11	54	5	57
1/4	1	12	0	36	3	14	16	7	08
5/16	1	30	0	45	3½	16	36	8	18
3/8	1	47	0	53	4	18	54	9	27
7/16	2	05	1	02	4½	21	14	10	37
1/2	2	23	1	11	5	23	32	11	46
3/4	3	35	1	47	6	28	4	14	2
15/16	4	28	2	14	7	32	31	16	16
1	4	45	2	23	8	36	52	18	26
1½	7	08	3	34	9	41	7	20	33
1¾	8	20	4	10	10	45	14	22	37
2	9	32	4	46	11	49	15	24	37

Taper Turning Attachment.—The illustration, Fig. 101A, shows an improved design of attachment for turning taper, and is fitted to the Dean, Smith, & Grace lathe. It is strongly made, designed on correct principles, and contains several unique features. It is possible to easily change from parallel to taper turning, or vice-versa, and as the taper attachment travels with the saddle, a taper can be turned anywhere in the length of bed. The guiding bar is graduated in degrees at one end, and in inches at the other, so that accurate adjustment can be quickly made, and tapers can be turned up to 9° from centre line of lathe.

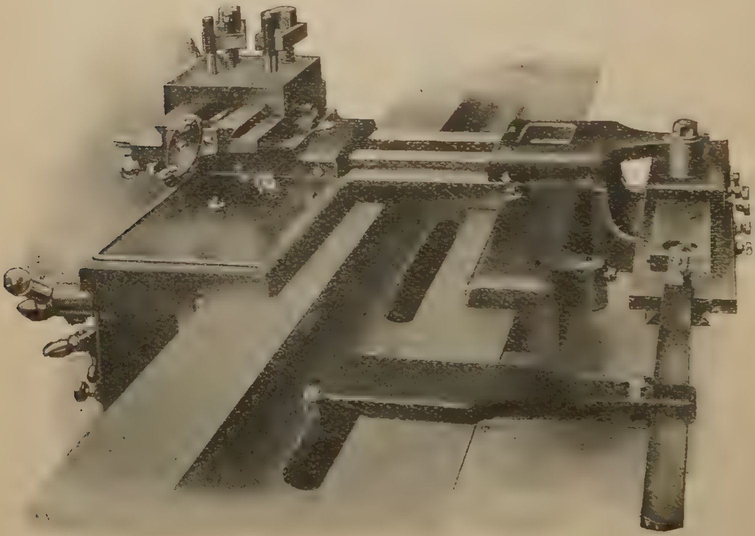


FIG. 101A.—Taper Turning Attachment.

With this type of attachment the cut can be put on with the surfacing screw, and the compound rest used as usual.

Holding Work.—Plain turning is held, as previously explained, by making centres in the ends of the work, and turning the work between the lathe centres. In order to get the centres perfectly true with the outside diameter of the work, the square centre, Fig. 102, can be used. This tool is placed in the loose head-stock spindle and the work p 14

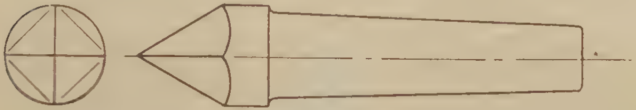


FIG. 102.—Square Centre.

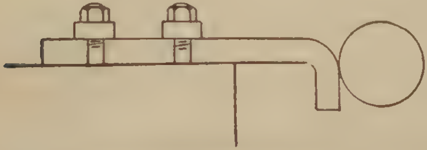


FIG. 103.—Square Centring.

revolved, a bent or forked bar being held in the slide rest, and then fed up to the work, Fig. 103. to scratch a [illegible] [illegible].

Pipe Work.—Wrought-iron and steel tubes that require to be turned or threaded externally can be conveniently held and driven between large centres, as illustrated in Fig. 104. This arrangement will often be

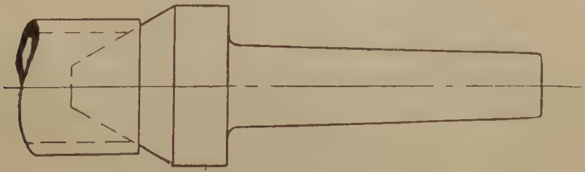


FIG. 104.—Pipe Centre.

found suitable when turning flanges on pipes, or taking cuts on the outside of small liners.

Plain Turning.—An example of plain turning is shown in Fig. 105. The front tool is used to rough down and finish where possible, the knife and parting tools being fed transversely to complete the work.

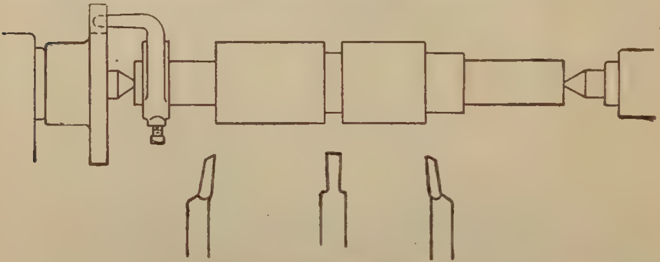


FIG. 105.—Plain Turning.

Mandrels.—The best class of mandrel is made from steel, correctly centred, hardened, and ground accurately to size. They are provided with flats at both ends to prevent the set screw of the driving carrier from slipping when being driven in the lathe.

Mandrel Work.—In order to use a mandrel it is necessary for the hole in the work to be slightly smaller than the mandrel, and therefore the mandrel must be slightly tapered. An example of the use of the mandrel is shown, Fig. 106, here. A three-cone pulley is forced on the mandrel and driven by means of a carrier.

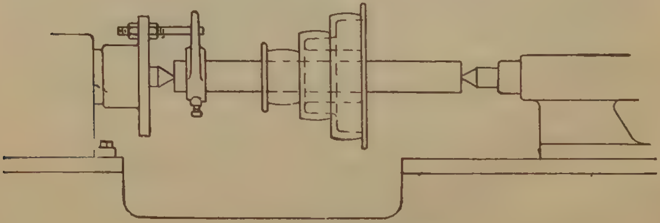


FIG. 106.—Mandrel Turning.

In order to take more than one diameter of work, mandrels are sometimes turned to two or more diameters.

There are also several forms of expanding mandrels which prove very useful on some classes of work.

To accurately turn work that has been screwed internally, a mandrel can have a thread cut to fit.

Chucks.—Work which requires to be bored or faced is often held in some form of chuck. These are to be found in endless variety. They are of two distinct kinds, those in which the jaws act independently of each other, and which are classed as independent jawed chucks, and those in which the jaws move simultaneously, and which are known as universal chucks. Another type of chuck, which is called a combination chuck, can be used for independent or self-centering purposes.

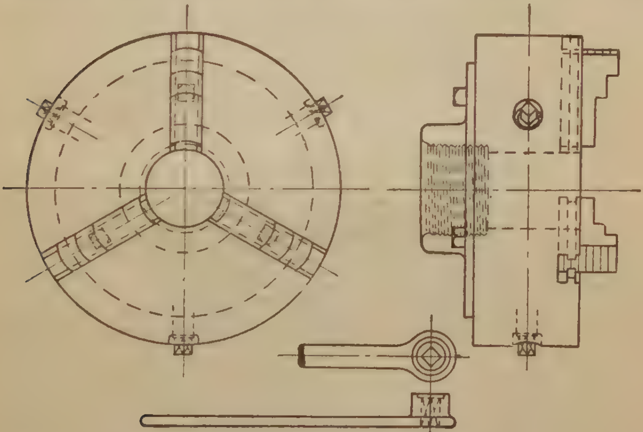


FIG. 107.—Self-Centering Chuck.

Fig. 107 illustrates a type of self-centering chuck, the jaws of which are stepped to take different sizes of work.

If necessary the jaws can be reversed, and thus a longer grip of the job can be taken

Drill Chucks, and some forms of two-jawed chucks, often have the bodies made from a solid piece of steel, having a taper shank to fit in the loose head-stock spindle.

The Face Plate is a circular plate threaded to fit the lathe spindle, and faced perfectly true. Holes and slots are made in the plate by means of which work can be bolted or clamped to it. In some face plate operations, such as boring, it is necessary to pack the work away from the face by means of parallel strips, so as to allow the boring tool to pass right through the work. Fig. 108 shows a pair of brasses packed off of the plate with strips, and clamped down by means of four plates.

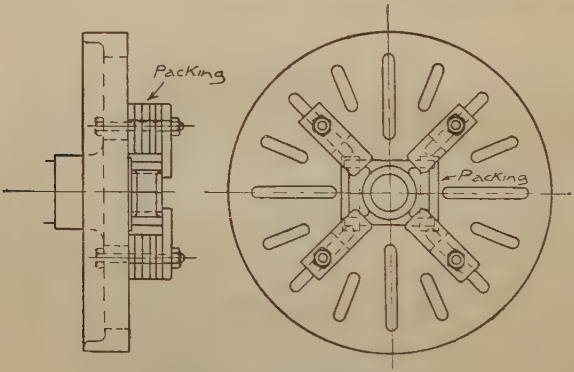


FIG. 108.—Boring Brasses.

Angle Plates.—In conjunction with the face plate, angle plates are frequently used. They are useful for facing or boring work where two or more faces are at right angles to each other. The angle plate is simply a cast-iron plate with two faces planed at right angles, and having slots in various positions for taking bolts.

When the work is more than a few pounds in weight, and is not revolving in the centre, a balance weight is bolted on the face plate in order to give a more even turning movement. This is illustrated in Fig. 109, where a method of using the angle plate is also shown.

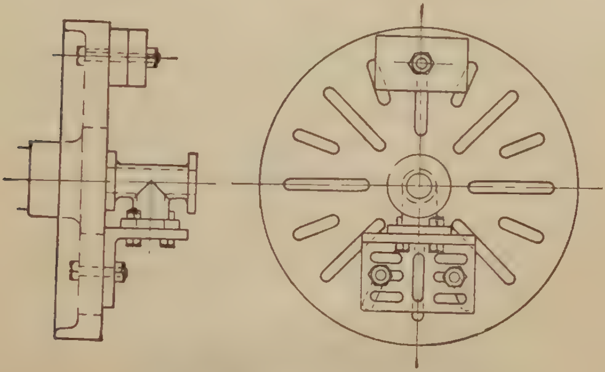


Fig. 109.—Using the Angle Plate.

Stays.—When long shafts are being turned, or long screws cut, it is necessary to support the work in some manner to prevent it springing, and for this purpose stays are used.

These may be either fixed or moving. Fig. 110 illustrates a form of fixed stay, called a central stay, which is

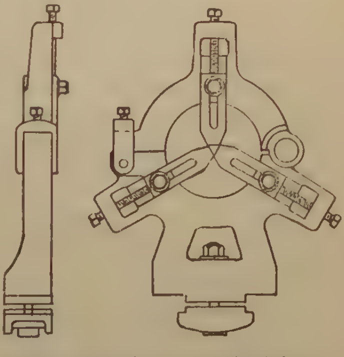


Fig. 110.—Centre or Fixed Stay.

bolted to the lathe bed, and the supporting arms adjusted to just touch the work, which is first turned at the part where the stay is to rub.

Travelling Stays, or finger stays, are attached to the lathe carriage, and move with the tool. The finger is adjusted to touch the work, and should be arranged to fit on the right-hand side of the tool if cutting from right to left. Fig. 111 illustrates one form of travelling stay.

Boring Work.—Work that is to be bored is frequently cored out; when that has not been done, it is necessary to first drill a hole for the boring tool to enter. For this purpose a drill made from square section steel can be used, the body of the drill being held in the lathe tool holder, or a twist drill can be placed in the loose headstock spindle.

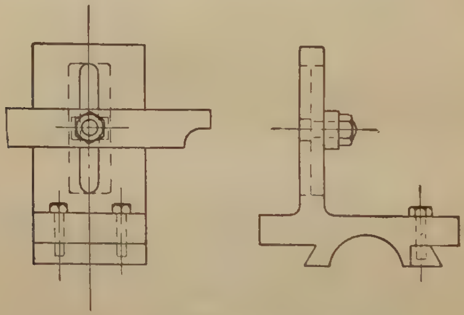


FIG. 111.—Travelling Stay.

For boring purposes many different forms of boring tools and bars are made. Before adjusting the tool, care must be taken to have the tool ground to give sufficient clearance, so that the cutting edge is the most prominent part when set up in the lathe. The amount of top rake depends upon the nature of the metal being cut; if hard steel or brass, very little top rake can be given, but for wrought iron or mild steel, a small amount of top rake will improve the cutting action of the tool. The correct height for all boring tools is when the cutting edge is level with the lathe centre, as shown in Fig. 112.

Jobs that are difficult to hold on the face plate or in the chuck, or which are too big to be swung in the lathe, are sometimes bored by means of a boring bar. To do this

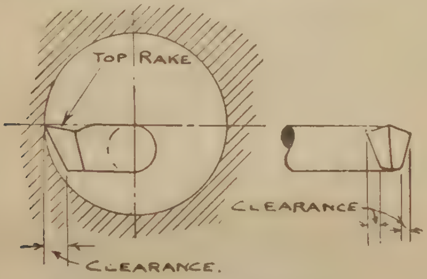


FIG. 112.—Setting of Boring Tool.

Saddle Boring

the top rests of the saddle are removed, and the work held directly on the saddle by means of bolts and plates. The boring bar revolves between the lathe centres, the cut being made by feeding the saddle forward. Engine cylinders and pump barrels are frequently bored in the ordinary lathe by this means.

Hand Turning in the Lathe

The graver or hand turning tool is made from square section steel, the cutting end being ground diamond shape.

Considerable practice is required before successful work can be done; the chief thing to aim at is to keep the cutting edge on a level with the lathe centre. These tools are mainly used for finishing radii, or parts where a specially formed tool would be otherwise required.

TAPERS AND ANGLES

Taper per Foot.	Included. <		With Centre Line.		Taper per Inch.	Taper per Inch from Centre Line.
	Deg.	Min.	Deg.	Min.		
$\frac{1}{8}$	0	36	0	18	·010416	·005203
$\frac{3}{16}$	0	54	0	27	·015625	·007812
$\frac{1}{4}$	1	12	0	36	·020833	·010416
$\frac{5}{16}$	1	30	0	45	·026042	·013021
$\frac{3}{8}$	1	47	0	53	·031250	·015625
$\frac{7}{16}$	2	5	1	2	·036458	·018229
$\frac{1}{2}$	2	23	1	11	·041667	·020833
$\frac{9}{16}$	2	42	1	21	·046875	·023438
$\frac{5}{8}$	3	...	1	30	·052084	·026042
$\frac{11}{16}$	3	18	1	39	·057292	·028646
$\frac{3}{4}$	3	25	1	47	·062500	·031250
$\frac{13}{16}$	3	52	1	56	·067708	·033854
$\frac{7}{8}$	4	12	2	6	·072917	·036456
$\frac{15}{16}$	4	28	2	14	·078125	·039063
1	4	45	2	23	·083330	·041667
$1\frac{1}{4}$	5	58	2	59	·104666	·052084
$1\frac{1}{2}$	7	8	3	34	·125000	·062500
$1\frac{3}{4}$	8	20	4	10	·145833	·072917
2	9	32	4	46	·166666	·083332
$2\frac{1}{2}$	11	54	5	57	·208333	·104166
3	14	16	7	8	·250000	·125000
$3\frac{1}{2}$	16	36	8	18	·291666	·145833
4	18	54	9	27	·333333	·166666
$4\frac{1}{2}$	21	14	10	37	·375000	·187500
5	23	32	11	46	·416666	·208333
6	28	6	14	3	·500000	·250000

CHAPTER XII

SCREWS AND SCREW CUTTING

FORMS of screw threads vary according to the purpose for which they are to be used, and also according to the country in which they are manufactured. The form of thread most frequently used for general engineering work is probably that known as the Whitworth thread. In 1841 Sir Joseph Whitworth proposed the adoption of a standard thread for bolts, and this system is chiefly used in Great Britain, Germany, and the United States.

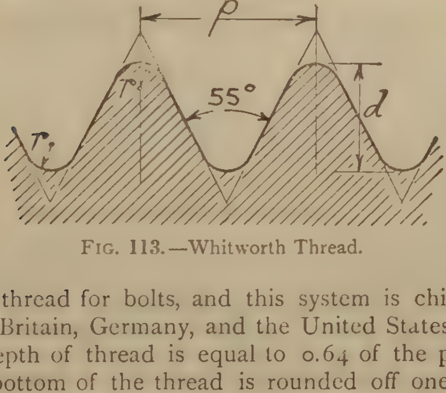


FIG. 113.—Whitworth Thread.

The depth of thread is equal to 0.64 of the pitch, the top and bottom of the thread is rounded off one-sixth of the depth, and the sides form an angle of 55°.

Fig. 113 shows the form of thread—

The formula being $p = \text{pitch} = \dfrac{1}{\text{Number of threads per inch}}$.

$d = \text{depth} = p \times 0{\cdot}6403.$ $r = \text{radius} = p \times 0{\cdot}1373.$

The British Association in 1881 adopted a system of screwed threads of small diameter. In this thread, which is only used for very small work, the thread angle is $47\frac{1}{2}°$, the depth 0.6 of the pitch; the top and bottom being rounded off two-elevenths of the pitch.

Fig. 114 shows the section of thread—

$$\text{The formula being } p = \text{pitch} = \frac{1}{\text{Number per millimetre}}.$$

$$d = \text{depth} = p \times 0{\cdot}6.$$

$$r = \text{radius} = \frac{2 \times p}{11}.$$

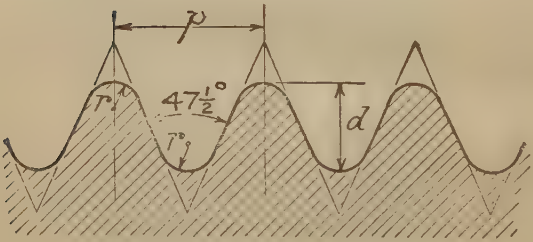


Fig. 114.—British Association Thread.

In the Sellers system of screwed threads the sides of the thread form an angle of 60°, and the top and bottom are truncated to form a flat one-eighth of the pitch.

This thread is shown in Fig. 115—

$$\text{The formula being } p = \text{pitch} = \frac{1}{\text{Number of threads per inch}}.$$

$$d = \text{depth} = p \times 0{\cdot}6495.$$

$$f = \text{flat} = \frac{p}{8}.$$

The above forms of threads are termed vee threads, and are used where parts of work are to be firmly and securely fastened together, the chief consideration being power, strength, durability; where other questions are involved it is necessary to rely upon a different form of thread.

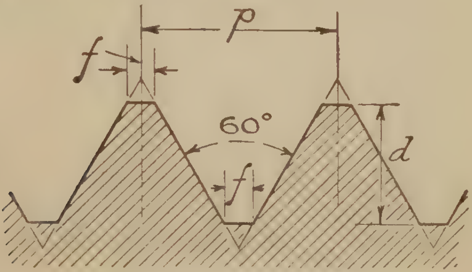


FIG. 115.—Sellers Thread.

Where forces act in one direction only, the buttress thread is sometimes adopted. It has one surface normal to the axis, but the shearing strength is twice as great as that of the square thread.

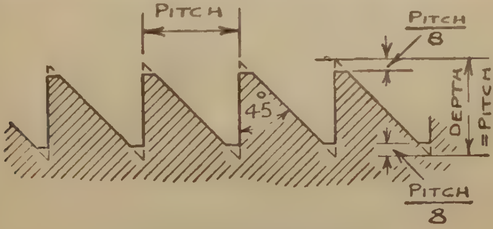


FIG. 116.—Buttress Thread.

A section of this thread is shown at Fig. 116.

Square Threads

Where it is necessary to obtain a quick travel or lead a square thread is often used. Theoretically, the depth and width of a square thread is half the pitch ; in practice this is slightly modified to suit the pitch and lead.

Definitions of a Screw

Geometrically the screw is the union of a plane cylinder having a circular base and a projecting ridge, of uniform shape throughout its length, wrapped on the surface of a cylinder in a regular spiral.

Pitch is the distance a nut would travel in one complete revolution if the screw had a single thread, or the distance between the centre of one thread and the centre of the next, measured in a line with its axis.

Lead is a term used when considering multiple threads, and is the distance a nut would travel in one complete revolution, or the distance from the centre of one thread to the centre of the same thread allowing for one complete turn.

Inclination of a thread is the angle formed by each of its superficial elements of depth, with a plane perpendicular to the axis of the screw. This inclination increases in proportion as the axis of the screw is approached. The pitch, on the contrary, remained constant.

Multiple Threads

Where coarse pitch threads are necessary, in order to bring the size of threads within workable and reasonable limits, multiple threads are employed. The difference between a single and double thread is in the advance or spiral, the pitch or lead of a double start thread being

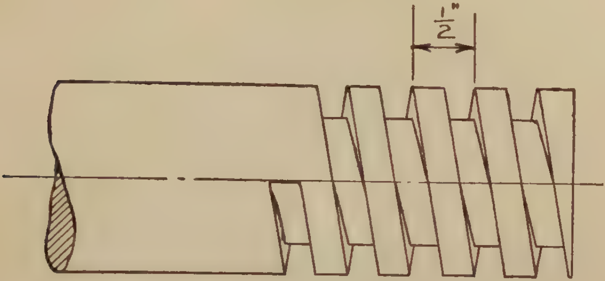


FIG. 117.—Right-Hand Square Thread.

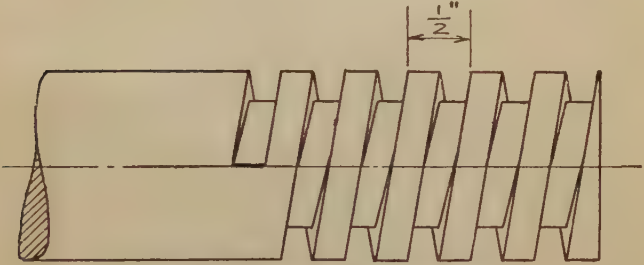


FIG. 118.—Left-Hand Square Thread.

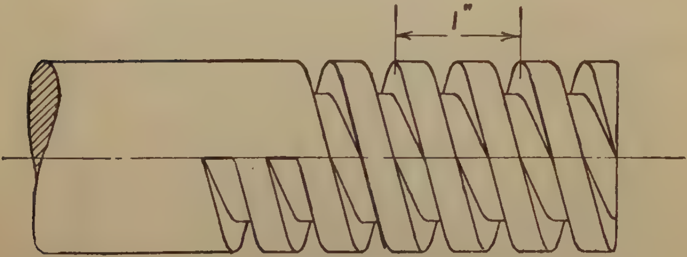


FIG. 119.—Double Right-Hand Thread.

twice that of a single start. Fig. 117 illustrates a single start right-hand thread of ½ in. pitch, or two threads per inch; Fig. 118 shows the same pitch of thread, left hand; Fig. 119 shows a double start right-hand thread of ½ in. pitch and 1 in. lead; Fig. 120 shows the same thread increased to a triple start of 1½ in. lead.

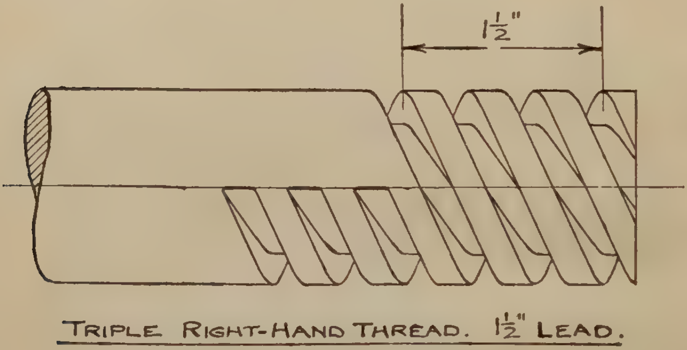


FIG. 120.—Triple Right-Hand Thread.

Right and Left Hand Thread

Screws may be made either right or left handed. A right-hand thread is one in which the nut must be turned in a right-handed direction to screw it on; a left-hand thread being one in which the nut would be screwed on by turning it to the left. Fig. 118 shows a left-hand thread.

Diameter of a Screw

The diameter of a screw is the measurement taken over the tops of the thread, and to obtain this measurement correctly it is often necessary to use special calipers having wide jaws.

To obtain the root diameter of a screw, it is necessary to use calipers having very thin jaws.

Measuring Pitch

The measurement of the pitch of fine threads is best accomplished by means of the screw pitch gauge. This is a tool having blades with notches of angular shape graded to the pitch stamped on the blade. The best form is that in which they can be used for internal and external testing. They are generally fitted with twenty or more blades, graded to measure between 9 and 40 threads per inch.

The Stock and Dies

Threads can be cut by several methods apart from the screw-cutting lathe.

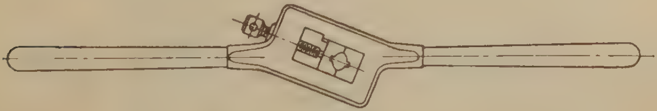


Fig. 121.—Stock and Dies.

For cutting threads on small work, where it is not convenient or necessary to do the job in the lathe, the stock and dies, Fig. 121, can often be used.

The stock is made from one piece of steel, the dies being in two parts, and usually fitting in a vee-shaped guide, being adjusted or screwed together by means of a set screw.

In using the stock and dies, the metal that is to be screwed is first turned to the exact diameter of the outside of the thread. The dies are then placed at the end of the metal and slightly tightened; they are then turned the distance required, and then turned back. This process is repeated until a full-sized thread is cut.

In using the dies care should be taken to keep the clearance spaces clear, and when cutting iron or steel, to keep the metal well lubricated with oil. It should be remembered that dies cut in one direction only, therefore they should be only tightened up just previous to the cutting movement.

Dies for Gas Threads

Stock and dies for cutting gas threads or tubes are used to a far greater extent than the Whitworth dies. With sizes below 2 inches it is usual to find a solid or one piece die used; above that size the split form of dies is more often used. In either case some form of guide is provided in order to keep the thread square with the axis of the tube.

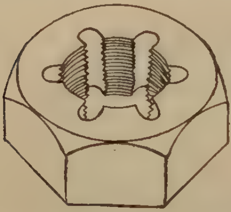


FIG. 122.—Hexagonal Die Nut.

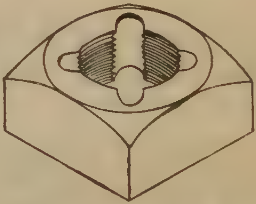


FIG. 123.—Square Die Nut.

Previous to using the gas dies it is necessary to grind or file the end of the tube slightly tapered, so as to allow the thread of the die to get a proper hold of the metal With the solid form of die the thread is cut in one operation.

Die Nuts

A die nut is a solid form of die, made square or hexagon in shape to fit a spanner, Figs. 122 and 123.

They may have Whitworth or gas threads, and are chiefly used for running down the threads of studs or bolts, which have become burred up after being fitted in their place, and thus obviating the removal of the stud. They are particularly useful for running down studs in cylinder covers and slide-valve chests, and for use where there is insufficient room to turn the stock and dies.

Tapping

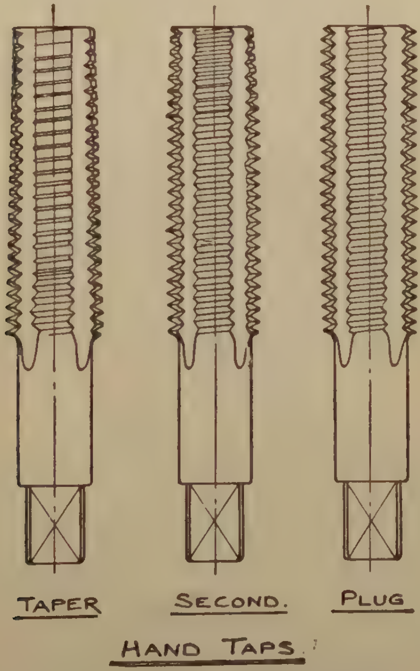


FIG. 124.—Set of Taps, Taper System.

Taps are used for the purpose of cutting internal threads either by hand or machine. Two different systems are in use, the taper and the parallel. Fig. 124 illustrates a set of taps on the taper system. When using this system of taps the taper or first tap is inserted in the hole and carefully turned by means of a tap wrench. When the bottom of the hole is reached, or the tap has gone the full length of the thread, it is removed, all chips of metal are blown out, and the second tap used; the process is repeated, and the thread can be finished by means of the plug tap.

With the parallel system the same process is gone through exactly, the difference being that the first tap used is not tapered, but is simply smaller in diameter the full length, and has a shallower thread; the second tap is slightly larger, and has a deeper thread, the last tap used being of full size, and the thread of full depth.

To find the correct diameter of a drill for drilling a hole to give a full Whitworth thread, multiply the pitch of the screw by 1.28, and subtract the product from the outside diameter.

Example.—Find the size of a drill to cut a hole for tapping a 1-in. Whitworth thread. Then—

$$\text{Eight threads per inch} = \tfrac{1}{8} \text{ in. pitch} = 0{\cdot}125.$$
$$0{\cdot}125 \times 1{\cdot}28 = 0{\cdot}16.$$
$$1{\cdot}0 - 0{\cdot}16 = 0{\cdot}84 \text{ or } \tfrac{21}{25}.$$

Size of drill required $\frac{21}{25}$, the nearest standard size being $\frac{27}{32}$ in.

Taps for cutting square threads are occasionally made, but owing to inaccuracies caused during the hardening process they cannot be relied upon.

A small alteration of pitch in the vee thread would not be noticeable, and if a slight difference were made in the diameter of the nut and bolt they would screw together; but with the square thread, if the pitch is slightly altered, no difference of diameter would allow the nut to fit.

To overcome the difficulties of hardening, it is common practice to make the spaces of the tap slightly larger than the correct width, but this tap cannot produce a correctly fitting nut, as only the first and last thread would be bearing on the thread of the nut.

Hand Chasers

Comb chasers for use by hand are made in pairs for internal and external work. Fig. 125 shows the inside chasers, and Fig. 126 the outside.

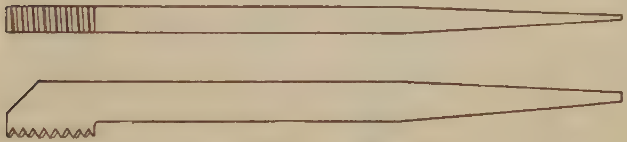


FIG. 125.—Inside Chaser.

The teeth are the exact formation or counterpart of the screw thread they are to cut. The teeth of chasers are formed by means of a hob, which is in itself a large duplicate of the screw.

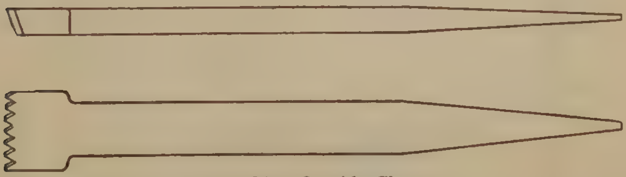


FIG. 126.—Outside Chaser.

Hand chasers are chiefly used for cutting small threads in brass, or for rounding off the tops and bottoms of threads that have been previously cut in the screw-cutting lathe. The ability to cut a thread on the solid metal by means of the chaser depends to a great extent on the dexterity of the workman.

In using the chaser a rest must be placed in the tool holder at such a height as to bring the cutting edge of the chaser level with the lathe centre. The handle of the chaser must be grasped firmly by the right hand, with the knuckles below, the left hand being round the head of the tool holder, with the thumb free to hold the end of the chaser. To obtain the thread, press firmly against the work, and at the same time, by a uniform movement, keep the chaser moving precisely the distance of one thread from the next. The cut can be regulated when making a start by pressure of the thumb on the end of the chaser. Care must be taken to keep the cutting edge of the tool parallel with the work, otherwise the thread will not be uniform in pitch.

Vee-shaped threads that have been cut by means of a vee tool in the screw-cutting lathe are frequently brought to their exact size by means of the chaser.

The Whitworth thread requires to be rounded top and bottom, and while it is possible to round the point of the tool, it is not possible to round the top of the thread by the same means. Therefore the chaser will give a more perfect shaped thread than can be obtained by means of the screw-cutting tool alone.

Change Wheels

For the purpose of cutting threads in the screw-cutting lathe, change wheels are provided. A full set generally consists of twenty-two wheels, rising from 20 to 100 by fives, and from 100 to 120 by tens, and containing two wheels of equal size, usually with 50 or 60 teeth which can be used when cutting a thread of the same pitch as the leading screw, and thereby doing away with the necessity of using a compound train.

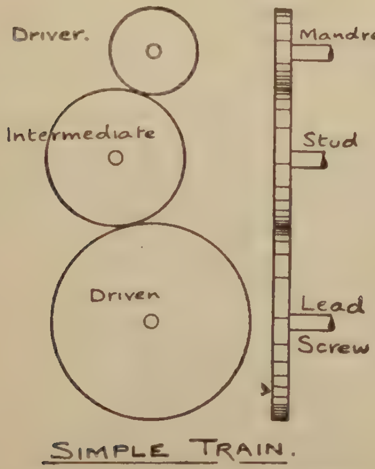


FIG. 127.—Simple Train of Wheels.

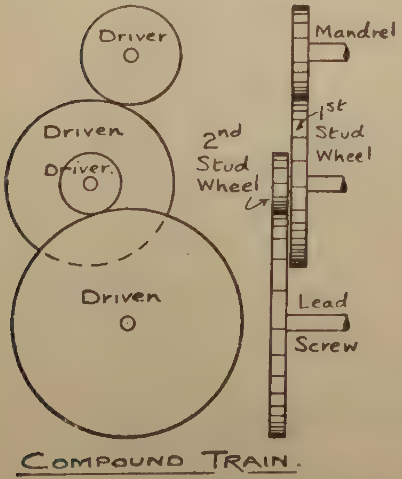


FIG. 128.—Compound Train of Wheels.

To calculate the wheels required for cutting a certain pitch screw, it is necessary to know how the ratio is obtained,

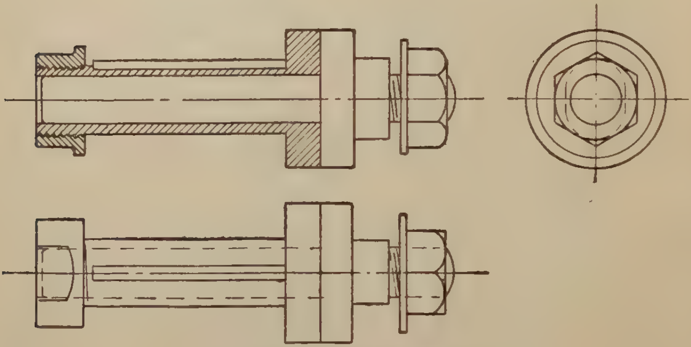


FIG. 129.—Stud for Change Wheels.

and exactly where the driving and driven wheels are to be placed.

Figs. 127 and 128 illustrate very clearly where the

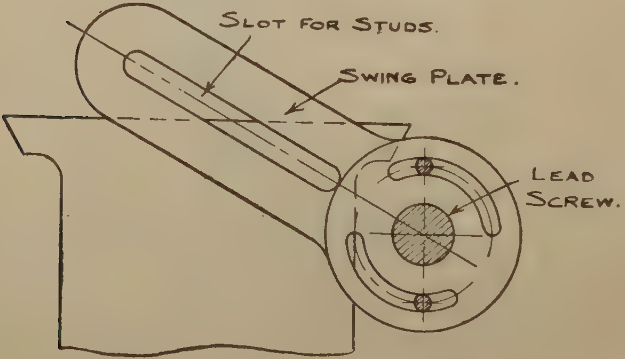


FIG. 130.—Swing Plate.

driving and driven wheels are placed. The first driving or mandrel wheel fits either directly on the lathe mandrel, or else on a small shaft from which it can be engaged with a wheel on the mandrel through the medium of a tumbler gear shown in Fig. 100.

The intermediate wheel fits on a movable stud as illustrated, Fig. 129, which can be secured in the desired position in the slot of a swing frame attached to the leading screw, Fig. 130.

The lead screw wheel fits directly on to the leading screw.

All wheels are fitted with keyways, the shafts having feathers of suitable size.

Ratio

The fundamental principle of screw-cutting being the ratio of the lead screw and the screw to be cut, before the change wheels can be found it is necessary to first find the ratio. In most cases it is a very simple matter, but when odd pitch screws have to be cut it is sometimes puzzling to the novice.

To find the ratio of driving and driven wheels the following always holds good :—As the number of threads per inch of the lead screw is to the number of threads per inch of the screw to be cut, so is the number of teeth in the mandrel wheel or driver to the number of teeth in the lead screw wheel as driven.

In a fractional form this would be—

$$\frac{\text{No. of threads per inch of leading screw}}{\text{No. of threads per inch of screw to be cut}} = \frac{\text{Wheel on mandrel}}{\text{Wheel on lead screw}}.$$

It will be seen from the above that whatever the pitch of the lead screw, if it is required to cut a screw of similar pitch, the ratio would be as 1 is to 1, and therefore any two wheels of equal number of teeth would do, with any wheel to gear up as shown in Fig. 131.

If twice the number of threads per inch or half the

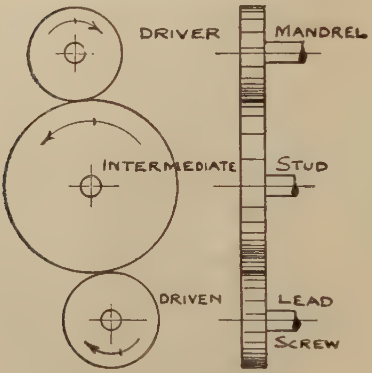


FIG. 131.—Change Wheels.

pitch of the lead screw is to be cut, then the driving or mandrel wheel would be half the size of the lead screw wheel, as shown in Fig. 132, or a ratio of 1 to 2

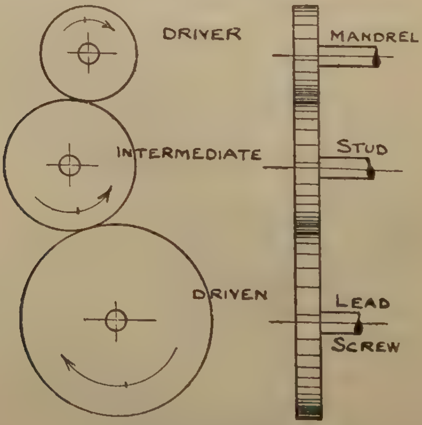


FIG. 132.—Change Wheels.

Should twice the pitch of the lead screw be required, then the driver or mandrel wheel would have to be twice the size of the driven wheel, as illustrated in Fig. 133, or a ratio of 2 to 1.

When working out change wheels remember:—If the pitch of the thread to be cut is greater than the pitch of the lead screw, then the driver or drivers multiplied together must be greater than the driving or driven multiplied together. In other words, if a finer thread is to be cut than on the lead, the work must revolve faster than the lead screw.

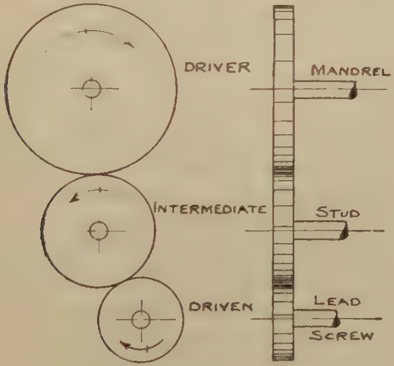


FIG. 133.—Change Wheels.

Examples of Change Wheels

Example 1.—It is required to cut a screw having $\frac{1}{4}$ in. pitch on a lathe with a lead screw of $\frac{1}{4}$ in. pitch. Then—

$$\frac{\frac{1}{4}\text{ in. pitch or four threads per inch}}{\frac{1}{4}\text{ in. pitch or four threads per inch}} = \frac{\text{driver}}{\text{driven}} = \frac{4}{4}.$$

In this example, and in any similar case in which the ratio is equal, or, in other words, when a screw is required having the same pitch as the lead, any two wheels having the same number of teeth will answer the purpose; one being placed on the lathe mandrel, the other on the lead screw, with any wheel to gear up.

Example 2.—It is required to cut a screw having $\frac{1}{4}$ in. pitch, or four threads per inch, on a lathe having a lead screw of $\frac{1}{2}$ in. pitch. Then—

$$\frac{\frac{1}{2}\text{ in. pitch or two threads per inch}}{\frac{1}{4}\text{ in. pitch or four threads per inch}} = \frac{\text{driver}}{\text{driven}} = \frac{2}{4},$$

or a ratio of 1 to 2, therefore any wheels of that ratio could be used. By multiplying both numbers by 20 we get 20 and 40, multiplying by 30 we get 30 and 60, multiplying by 40 we get 40 and 80. Therefore any of these numbers can be used, the smallest being the driver, and being placed on the lathe mandrel.

Example 3.—It is required to cut a screw having $\frac{1}{20}$ in. pitch, or twenty threads per inch, on a lathe having a lead screw of $\frac{1}{4}$ in. pitch or four threads per inch. Then—

$$\frac{\frac{1}{4}\text{ in. pitch or four threads per inch}}{\frac{1}{20}\text{ in. pitch or twenty threads per inch}} = \frac{\text{driver}}{\text{driven}} = \frac{4}{20},$$

or a ratio of 1 to 5, therefore any wheels having teeth in that ratio can be used. Multiplying by 20 we get 20 and 100; therefore 20 driver, 100 driven.

Example 4.—It is required to cut a screw having 1 in. pitch on a lathe having a lead screw of $\frac{1}{4}$ in. pitch. Then—

$$\frac{\frac{1}{4}\text{ in. pitch or four threads per inch}}{1\text{ in. pitch or one thread per inch}} = \frac{\text{driver}}{\text{driven}} = \frac{4}{1},$$

or a ratio of 4 to 1. Multiplying by 20 we get 80 and 20, multiplying by 25 we get 100 and 25, multiplying by 30 we get 120 and 30. Therefore any of these pairs can be used, the largest wheel driving.

Fractional Pitches

When calculating change wheels for fractional pitches, it is best to work on the universal rule for finding ratio, which is:—

Find the distance in inches which contain the minimum number of complete threads in the screw to be cut, and also the number of threads in a similar distance on the lead screw. The result will be the ratio that is required between the driver and the driven wheels. To take an example, if a screw having a pitch of $2\frac{7}{8}$ in. is to be cut on a lathe having $\frac{1}{4}$ in. pitch lead screw, find the ratio.

A screw having a pitch of $2\frac{7}{8}$ in. would have eight complete threads in 23 inches; on the same distance of the lead screw there would be ninety-two complete threads. Therefore the ratio would be as 92 is to 8, or as 23 is to 2.

To take another example. If a screw having $1\frac{7}{8}$ threads per inch is to be cut on a lathe having a lead screw of four threads per inch, find the ratio. A screw having $1\frac{7}{8}$ threads per inch would have fifteen complete threads in 8 inches; on the same distance of the lead screw there would be thirty-two complete threads. Therefore, the ratio would be as 32 is to 15.

Example 5.—It is required to cut a screw having $9\frac{1}{2}$ threads to the inch on a lathe having $\frac{1}{4}$ in. pitch lead screw. Then—

$$\frac{\frac{1}{4}\text{ in. pitch or eight threads in 2 in.}}{\frac{1}{9\frac{1}{2}}\text{ in. pitch or nineteen threads in 2 in.}}=\frac{\text{driver}}{\text{driven}}=\frac{8}{19},$$

or a ratio of 8 to 19. Multiplying by 5 we get 40 and 95. Therefore, 40 driver, 95 driven.

Example 6.—It is required to cut a screw having $1\frac{1}{4}$ in. pitch on a lathe having a lead screw of $\frac{1}{4}$ in. pitch. Then—

$$\frac{\frac{1}{4}\text{ in. pitch or twenty threads in 5 in.}}{1\frac{1}{4}\text{ in. pitch or four threads in 5 in.}}=\frac{\text{driver}}{\text{driven}}=\frac{20}{4},$$

or a ratio of 5 to 1. Multiplying by 20 we get 100 and 20. Therefore, 100 driver or mandrel wheel, 20 driven or lead screw wheel.

Example 7.—It is required to cut a screw having $3\frac{1}{2}$ threads per inch on a lathe having a lead screw of $\frac{1}{2}$ in. pitch. Then—

$$\frac{\frac{1}{2}\text{ in. pitch or four threads in 2 in.}}{\frac{1}{3\frac{1}{2}}\text{ in. pitch or seven threads in 2 in.}} = \frac{\text{driver}}{\text{driven}} = \frac{4}{7}.$$

The ratio being as 4 is to 7, multiplying by 5 we get 20 and 35. Therefore, 20 driver or mandrel wheel, 35 driven or lead screw wheel.

Examples of Compound Gear

As it is not always possible to obtain the required ratio by means of a simple train of wheels, a compound train must be used, Fig. 128.

To take an example. It is required to cut a screw having two threads per inch on a lathe having a lead screw of two threads per inch, when the lathe is not supplied with two wheels of the same size.

In this case the ratio is equal, and any two wheels of the same size could be used. As the lathe is not supplied with two wheels of the same size a compound train must be used. This can be obtained by having two 2 to 1 gears. Thus—

$$\frac{2}{1} \times \frac{1}{2},$$

and then multiplying by any suitable number. Multiplying by 20 and 50 we get—

$$\frac{40}{20} \times \frac{50}{100}.$$

Therefore, 40 and 50 drivers, 20 and 100 driven.

Example 8.—It is required to cut a screw having twenty-five threads per inch on a lathe having a lead screw of four threads per inch. Then—

$$\frac{\frac{1}{4}\text{ in. pitch or four threads per inch}}{\frac{1}{25}\text{ in. pitch or twenty-five threads per inch}}=\frac{\text{driver}}{\text{driven}}=\frac{4}{25}.$$

Multiplying 4 × 5 = 20, this being the smallest wheel in the set, it cannot be reduced, and multiplying 25 × 5 = 125, which in many cases is too large by 5; that being so, a compound train must be used.

To obtain the wheels put down the ratio, and multiply both figures by any suitable number, in this case by 10 and 100, thus—

$$\frac{40}{250}\times\frac{100}{100},$$

and then cancel to obtain suitable wheels, by dividing by 5, thus—

$$\frac{40}{\underset{50}{\cancel{250}}}\times\frac{\overset{20}{\cancel{100}}}{100}.$$

Then 40 and 20 drivers, 50 and 100 driven.

Example 9.—It is required to cut a screw having forty-five threads per inch on a lathe having a lead screw of four threads per inch. Then—

$$\frac{\frac{1}{4}\text{ in. pitch or four threads per inch}}{\frac{1}{45}\text{ in. pitch or forty-five threads per inch}}=\frac{\text{driver}}{\text{driven}}=\frac{4}{45}.$$

Multiplying by 10 and 100, and dividing by 5, thus—

$$\frac{40}{\underset{90}{\cancel{450}}}\times\frac{\overset{20}{\cancel{100}}}{100}=\frac{40}{90}\times\frac{20}{100}.$$

Then 40 and 20 drivers, 90 and 100 driven.

Change Wheels for Multiple Threads

In order to cut multiple threads, it is usual to choose a first driving wheel that can be divided equally by the number of different threads or starts in the screw to be cut. For example, to cut a double-threaded screw, any first driver would be used that had an even number of teeth; to cut a triple, any first driver would do that would divide equally by 3, such as 30, 60, or 90 would do.

Example 10.—A compound thread having a lead of $1\frac{1}{2}$ in. is to be cut on a lathe having a lead screw of $\frac{1}{4}$ in. pitch. Then—

$$\frac{\frac{1}{4}\text{ in. pitch or twelve threads in } 3}{1\frac{1}{2}\text{ in. pitch or two threads in } 3}=\frac{12}{2}.$$

The ratio is 6 to 1. Multiplying by 20 we get 120 and 20, and as 120 will divide equally by 2, it would be a suitable gear.

Example 11.—A five-start thread having a lead of $2\frac{1}{2}$ in. is required to be cut on a lathe having a lead screw of two threads per inch. Then—

$$\frac{\frac{1}{2}\text{ in. pitch or ten threads in 5 in.}}{2\frac{1}{2}\text{ in. pitch or two threads in 5 in.}}=\frac{10}{2}.$$

The ratio being as 5 is to 1. Multiplying by 20 we get 100 and 20, and as 100 can be divided equally by 5, it would be a suitable gear.

Prime Numbers

In finding the ratio for cutting certain pitch screws, it will sometimes occur that none of the change wheels in the set contain the required number of teeth. This is owing to the fact that prime numbers are required.

To take an example. It is required to cut a screw having thirty-one threads per inch on a lathe having a lead screw of two threads per inch.

The ratio is as 2 is to 31. Multiplying by 10 and 80, and dividing by 2, we get

$$\frac{20}{\underset{155}{\cancel{310}}} \times \frac{\overset{40}{\cancel{80}}}{80} = \frac{20}{155} \times \frac{40}{80}.$$

155 being the lowest figure to which we can bring the 31, it would require a special wheel to cut the thread required.

The following is a list of prime numbers between 23 and 100:—29, 31, 37, 41, 43, 47, 53, 59, 61, 67, 71, 73, 79, 83, 89, and 97, and with these no time should be wasted in attempting to factorise.

Approximations for Fractional Threads

When it is required to cut a thread, the ratio of which cannot be factorised, two methods can be adopted. By one a special wheel can be cut, and by the other the terms of the ratio can be altered slightly, and by that means an approximation can be obtained.

If accuracy is necessary, and it often is with fractional pitches, then a special wheel must be cut; if a slight inaccuracy can be allowed, then the following method can be followed:—

Example.—It is required to cut a thread having 67.7 threads in 12 in. on a lathe having a lead screw of ½ in. pitch. Then—

$$\frac{\frac{1}{2}\text{ in. pitch or 24 threads in 12 in.}}{\frac{12}{67\cdot7}\text{ in. pitch or 67·7 threads in 12 in.}} = \frac{24}{67\cdot7} = \frac{240}{677},$$

or a ratio of 240 to 677.

As 677 will not factorise, by adding 3 we get a ratio of 240 to 680. This can be expressed as

$$\frac{12 \times 20}{17 \times 40}.$$

Multiplying the 12 and 17 by 5 we get

$$\frac{60 \times 20}{85 \times 40}.$$

Then 60 and 20 drivers, 85 and 40 driven.

Metric Pitches

Cutting threads approximately to metric pitches on an ordinary lathe is very simple. The metre is 39.37 in., or about $\frac{1}{200}$ of an inch less than $39\frac{3}{8}$ in., and this difference can be neglected.

As there are 1,000 mm. in the metre (or $39\frac{3}{8}$ in.), there are 8,000 mm. in $39\frac{3}{8} \times 8 = 315$ in., and assuming a lead screw of $\frac{1}{2}$ in. pitch, this would be equivalent to $315 \times 2 = 630$ threads in 8,000 mm.

Example.—If a screw of 1 mm. pitch was required, the ratio between the required screw and the leading screw would be

$$630 : 8000 :: 63 : 800.$$

As 1 mm. is less than the pitch of the leading screw, the smaller wheel drives the greater.

Thus, for working out the change wheels for any screw of millimetre pitch, this fraction is a constant number, and a special wheel having 63 teeth, termed a translating wheel, must be used.

To find the change wheels, multiply the constant by the pitch of the screw required.

Example.—Find the change wheels to cut a thread of 5 mm. pitch. Then—

$$\frac{63}{800} \times 5 = \frac{63}{80} \times \frac{5}{10}.$$

By adding ciphers to the numbers 5 and 10 we get

$$\frac{63 \times 50}{80 \times 100}.$$

Therefore 63 and 50 drivers, 80 and 100 driven.

TABLE OF CHANGE WHEELS FOR CUTTING VARIOUS THREADS

Lead Screw ½ in. Pitch

Threads to be cut per Inch.	Drivers.	Driven.	Threads to be cut per Inch.	Drivers.	Driven.
1	80	40	7½	20	75
1⅛	80	45	8	20	80
1¼	80	50	9	20	90
1⅜	80	55	10	20	100
1½	80	60	11	20	110
1⅝	60 100	75 65	12	20	120
1¾	80	70	13	20 50	65 100
1⅞	80	75	14	20 75	100 105
2	60	60	15	20 80	100 120
2¼	40	45	16	25 30	50 120
2⅜	80	95	17	20 60	85 120
2½	40	50	18	25 40	75 120
2⅝	80	105	19	25 40	95 100
2¾	40	55	20	20 40	80 100
2⅞	40 100	115 25	21	20 40	70 120
3	40	60	22	20 30	60 110
3¼	40	65	23	20 50	100 115
3½	40	70	24	25 30	75 120
4	30	60	25	20 30	75 100
4½	40	90	26	20 25	65 100
5	30	75	28	20 25	70 100
5½	20	55	30	24 40	100 120
6	30	90	35	20 30	100 105
6½	20	65	40	20 30	100 120
7	20	70	50	20 20	100 100

Change Wheels for Cutting Millimetre Pitch

Lead Screw ½ in. Pitch

Threads to be cut in Millimetres.	Drivers.	Driven.	Threads to be cut in Millimetres.	Drivers.	Driven.
1	36 35	160 100	6	63 60	100 80
2	63 20	100 80	7	63 70	100 80
3	63 30	100 80	8	63 80	100 80
4	63 40	100 80	9	63 90	100 80
5	63 50	100 80	10	63 100	100 80

Table of Change Wheels for Cutting Various Pitch Threads

Lathe Lead Screw ¼ in. Pitch

Threads to be cut per Inch.	Drivers.	Driven.	Threads to be cut per Inch.	Drivers.	Driven.
1	100	25	7½	40	75
1⅛	60 80	45 30	8	40	80
1¼	80	25	9	40	90
1⅜	80 120	110 30	10	40	100
1½	80	30	11	40	110
1⅝	60 80	65 30	12	40	120
1¾	80	35	13	20	65
1⅞	40 80	50 30	14	20	70
2¼	40 100	75 30	15	20	75
2⅜	40 100	95 25	16	20	80
2½	80	50	17	20	85
2⅝	40 100	105 25	18	20	90
2¾	80	55	19	20	95
2⅞	40 100	115 25	20	20	100
3	80	60	21	20 40	60 70
3¼	80	65	22	20	110
3½	40	35	23	20	115
4	40	40	24	20	120
4¼	40	45	25	30 40	75 100
5	40	50	26	20 30	60 65
5½	40	55	28	20 30	40 105
6	30	45	30	20 60	90 100
6½	40	65	40	20 55	100 110
7	40	70	50	20 30	75 100

To Prove a Train of Wheels

If the train of wheels is a simple one, divide the number of teeth in the driven or lead screw wheel by the number of teeth in the mandrel wheel or driver, and multiply by the number of threads per inch in the lead screw.

To take an example. A train of wheels has 40 teeth in the driving wheel, and 20 in the driven, the lead screw of the lathe having four threads per inch. Find the number of threads being cut. Then—

$$20 \div 40 = 0{\cdot}5.$$
$$0{\cdot}5 \times 4 = 2, \text{ or two threads per inch.}$$

In a compound train multiply the driving wheels together and the driven wheels together, and divide the product of the driven by the product of the drivers. The quotient multiplied by the number of threads per inch on the lead screw will give the number of threads being cut.

Example.—A compound train of wheels having 40 and 50 drivers, with 125 and 100 driven, with a lead screw of four threads per inch. Find the thread being cut. Then—

$$\frac{125 \times 100}{40 \times 50} = \frac{25}{4} = 6{\cdot}25.$$
$$6{\cdot}25 \times 4 = 25.$$

Or the lathe will be set to cut twenty-five threads per inch.

BRITISH STANDARD FINE SCREW THREAD

(Recommended by the Engineering Standards Committee as a standard for screws subjected to shock and vibration, or where extra strength of core is required.)

Full Diameter in Inches.	Number of Threads per Inch.	Pitch in Inches.	Full Diameter in Inches.	Number of Threads per Inch.	Pitch in Inches.
$\frac{1}{4}$ (0·25)	25	0·0400	*$2\frac{7}{8}$ (2·875)	6	0·1667
$\frac{5}{16}$ (0·3125)	22	0·0455	3	5	0·2000
$\frac{3}{8}$ (0·375)	20	0·0500	*$3\frac{1}{8}$ (3·125)	5	0·2000
$\frac{7}{16}$ (0·4375)	18	0·0556	$3\frac{1}{4}$ (3·25)	5	0·2000
$\frac{1}{2}$ (0·5)	16	0·0625	$3\frac{3}{8}$ (3·375)	5	0·2000
$\frac{9}{16}$ (0·5625)	16	0·0625	$3\frac{1}{2}$ (3·5)	4·5	0·2222
$\frac{5}{8}$ (0·625)	14	0·0714	*$3\frac{5}{8}$ (3·625)	4·5	0·2222
$\frac{11}{16}$ (0·6875)	14	0·0714	$3\frac{3}{4}$ (3·75)	4·5	0·2222
$\frac{3}{4}$ (0·75)	12	0·0833	*$3\frac{7}{8}$ (3·875)	4·5	0·2222
$\frac{13}{16}$ (0·8125)	12	0·0833	4	4·5	0·2222
$\frac{7}{8}$ (0·875)	11	0·0909	*$4\frac{1}{8}$ (3·125)	4·5	0·2222
*$\frac{15}{16}$ (0·9375)	11	0·0909	*$4\frac{1}{4}$ (4·25)	4	0·2500
1	10	0·1000	$4\frac{3}{8}$ (4·375)	4	0·2500
$1\frac{1}{8}$ (1·125)	9	0·1111	$4\frac{1}{2}$ (4·5)	4	0·2500
$1\frac{1}{4}$ (1·25)	9	0·1111	*$4\frac{5}{8}$ (4·625)	4	0·2500
$1\frac{3}{8}$ (1·375)	8	0·1250	*$4\frac{3}{4}$ (4·75)	4	0·2500
$1\frac{1}{2}$ (1·5)	8	0·1250	*$4\frac{7}{8}$ (4·875)	4	0·2500
$1\frac{5}{8}$ (1·625)	8	0·1250	5	4	0·2500
$1\frac{3}{4}$ (1·75)	7	0·1429	*$5\frac{1}{8}$ (5·125)	4	0·2500
*$1\frac{7}{8}$ (1·875)	7	0·1429	*$5\frac{1}{4}$ (5·25)	3·5	0·2857
2	7	0·1429	*$5\frac{3}{8}$ (5·375)	3·5	0·2857
$2\frac{1}{8}$ (2·125)	7	0·1429	$5\frac{1}{2}$ (5·5)	3·5	0·2857
$2\frac{1}{4}$ (2·25)	6	0·1667	*$5\frac{5}{8}$ (5·625)	3·5	0·2857
*$2\frac{3}{8}$ (2·375)	6	0·1667	*$5\frac{3}{4}$ (5·75)	3·5	0·2857
$2\frac{1}{2}$ (2·5)	6	0·1667	*$5\frac{7}{8}$ (5·875)	3·5	0·2857
*$2\frac{5}{8}$ (2·625)	6	0·1667	6	3·5	0·2857
$2\frac{3}{4}$ (2·75)	6	0·1667			

* The Committee recommend that for general use these sizes be dispensed with.

WHITWORTH GAS THREADS

Size.	Diameter at Top of Thread.	Diameter at Bottom of Thread	Number of Threads per Inch.	Size.	Diameter at Top of Thread.	Diameter at Bottom of Thread.	Number of Threads per Inch.
Inch.	Inch.	Inch.		Inch.	Inch.	Inch.	
$\frac{1}{8}$	0·3825	0·3367	28	$1\frac{5}{8}$	2·021	1·905	11
$\frac{1}{4}$	0·518	0·4506	19	$1\frac{3}{4}$	2·047	1·9305	11
$\frac{3}{8}$	0·6563	0·5889	19	$1\frac{7}{8}$	2·245	2·1285	11
$\frac{1}{2}$	0·8257	0·7342	14	2	2·347	2·2305	11
$\frac{5}{8}$	0·9022	0·8107	14	$2\frac{1}{4}$	2·5875	2·471	11
$\frac{3}{4}$	1·041	0·9495	14	$2\frac{1}{2}$	3·0013	2·8848	11
$\frac{7}{8}$	1·189	1·0975	14	$2\frac{3}{4}$	3·247	3·1305	11
1	1·309	1·1925	11	3	3·485	3·3685	11
$1\frac{1}{8}$	1·492	1·3755	11	$3\frac{1}{4}$	3·6985	3·582	11
$1\frac{1}{4}$	1·65	1·5335	11	$3\frac{1}{2}$	3·912	3·7955	11
$1\frac{3}{8}$	1·745	1·6285	11	$3\frac{3}{4}$	4·1255	4·009	11
$1\frac{1}{2}$	1·8825	1·765	11	4	4·339	4·223	11

APPROXIMATE SIZES OF GAS THREADS IN INCHES

Size.	Diameter at Top of Thread.	Diameter at Bottom of Thread.	Number of Threads per Inch.	Size.	Diameter at Top of Thread.	Diameter at Bottom of Thread.	Number of Threads per Inch.
Inch.	Inch.	Inch.		Inch.	Inch.	Inch.	
$\frac{1}{8}$	$\frac{3}{8}$	$\frac{5}{16}+\frac{1{\cdot}5}{64}$	28	$1\frac{5}{8}$	$2\frac{1}{64}$	$1\frac{7}{8}+\frac{1}{32}$	11
$\frac{1}{4}$	$\frac{1}{2}+\frac{1}{64}$	$\frac{7}{16}+\frac{1}{64}$	19	$1\frac{3}{4}$	$2\frac{3}{64}$	$1\frac{15}{16}$	11
$\frac{3}{8}$	$\frac{5}{8}+\frac{1}{32}$	$\frac{1}{2}+\frac{3}{32}$	19	$1\frac{7}{8}$	$2\frac{1}{4}$	$2\frac{1}{8}$	11
$\frac{1}{2}$	$\frac{13}{16}+\frac{1}{64}$	$\frac{11}{16}+\frac{3}{64}$	14	2	$2\frac{5}{16}+\frac{1}{32}$	$2\frac{3}{16}+\frac{3}{64}$	11
$\frac{5}{8}$	$\frac{7}{8}+\frac{1}{32}$	$\frac{13}{16}$	14	$2\frac{1}{4}$	$2\frac{9}{16}+\frac{1}{32}$	$2\frac{7}{16}+\frac{1}{32}$	11
$\frac{3}{4}$	$1\frac{1}{32}$	$\frac{15}{16}$	14	$2\frac{1}{2}$	3	$2\frac{7}{8}$	11
$\frac{7}{8}$	$1\frac{1}{16}$	$1\frac{3}{32}$	14	$2\frac{3}{4}$	$3\frac{1}{4}$	$3\frac{1}{8}$	11
1	$1\frac{5}{16}$	$1\frac{3}{16}$	11	3	$3\frac{7}{16}+\frac{2}{64}$	$3\frac{5}{16}+\frac{3{\cdot}6}{64}$	11
$1\frac{1}{8}$	$1\frac{7}{16}+\frac{3{\cdot}5}{64}$	$1\frac{3}{8}$	11	$3\frac{1}{4}$	$3\frac{11}{16}+\frac{1}{64}$	$3\frac{9}{16}+\frac{1}{64}$	11
$1\frac{1}{4}$	$1\frac{5}{8}+\frac{1}{32}$	$1\frac{1}{2}+\frac{1}{32}$	11	$3\frac{1}{2}$	$3\frac{7}{8}+\frac{1}{32}$	$3\frac{3}{4}+\frac{3}{64}$	11
$1\frac{3}{8}$	$1\frac{3}{4}$	$1\frac{5}{8}$	11	$3\frac{3}{4}$	$4\frac{1}{8}$	4	11
$1\frac{1}{2}$	$1\frac{7}{8}$	$1\frac{3}{4}+\frac{1}{64}$	11	4	$\frac{5}{16}+\frac{1}{32}$	$4\frac{3}{16}+\frac{1}{32}$	11

British Association Screw Threads

Schedule of Sizes

Designating Number.	Full Diameter.	Approximate Full Diameter in Inches.	Pitch.	Effective Diameter.	Core Diameter.
	Mm.		Mm.	Mm.	Mm.
0	6·0	0·236	1·0	5·4	4·8
1	5·3	0·209	0·9	4·76	4·22
2	4·7	0·185	0·81	4·215	3·73
3	4·1	0·161	0·73	3·66	3·22
4	3·6	0·142	0·66	3·205	2·81
5	3·2	0·126	0·59	2·845	2·49
6	2·8	0·110	0·53	2·48	2·16
7	2·5	0·098	0·48	2·21	1·92
8	2·2	0·087	0·43	1·94	1·68
9	1·9	0·075	0·39	1·665	1·43
10	1·7	0·067	0·35	1·49	1·28
11	1·5	0·059	0·31	1·315	1·13
12	1·3	0·051	0·28	1·13	0·96
13	1·2	0·047	0·25	1·05	0·9
14	1·0	0·039	0·23	0·86	0·72
15	0·9	0·035	0·21	0·775	0·65
16	0·79	0·031	0·19	0·675	0·56
17	0·70	0·028	0·17	0·6	0·50
18	0·62	0·024	0·15	0·53	0·44
19	0·54	0·021	0·14	0·455	0·37
20	0·48	0·019	0·12	0·41	0·34
21	0·42	0·017	0·11	0·355	0·29
22	0·37	0·015	0·10	0·31	0·25
23	0·33	0·013	0·09	0·275	0·22
24	0·29	0·011	0·08	0·24	0·19
25	0·25	0·010	0·07	0·21	0·17

The figures in column 3 are given for convenience only, and should, in no case, be worked to where satisfactory interchangeability is required.

WHITWORTH'S STANDARD TAPS

Outside Diameter.	Full Length.	Length of Screw Part.	Length of Square.	Size of Square.	Diameter at Bottom of Thread.	Threads per Inch.
1/16	1 1/2	5/8	3/16	...	0·0413	60
3/32	1 5/8	3/4	3/16	..	0·0671	48
1/8	1 3/4	7/8	1/4	...	0·093	40
5/32	1 7/8	7/8	1/4	...	0·112	32
3/16	2	1	5/16	...	0·134	24
7/32	2 1/8	1 1/16	5/16	...	0·165	24
1/4	2 1/4	1 1/8	3/8	...	0·186	20
5/16	2 1/2	1 3/8	7/16	5/32	0·241	18
3/8	2 3/4	1 1/2	1/2	7/32	0·295	16
7/16	3 1/4	1 3/4	1/2	9/32	0·346	14
1/2	3 1/2	2	9/16	5/16	0·393	12
9/16	3 3/4	2 1/8	9/16	5/16	0·455	12
5/8	4	2 1/4	5/8	3/8	0·508	11
11/16	4 1/4	2 3/8	11/16	3/8	0·571	11
3/4	4 1/2	2 1/2	3/4	7/16	0·622	10
13/16	4 3/4	2 5/8	3/4	7/16	0·684	10
7/8	5	2 7/8	13/16	1/2	0·732	9
15/16	5 1/4	3	13/16	1/2	0·795	9
1	5 1/2	3 1/4	7/8	5/8	0·84	8
1 1/8	6	3 1/2	1	11/16	0·942	7
1 1/4	6 1/2	3 3/4	1 1/8	13/16	1·067	7
1 3/8	7 1/2	4 1/4	1 1/8	13/16	1·161	6
1 1/2	8	4 3/4	1 1/4	1	1·286	6
1 5/8	8 1/2	5 1/4	1 1/4	1	1·368	5
1 3/4	9	5 1/2	1 3/8	1 1/8	1·494	5
1 7/8	9 1/2	5 3/4	1 3/8	1 1/8	1·59	4 1/2
2	10	6	1 1/2	1 5/16	1·715	4 1/2
2 1/8	10 1/2	6 1/4	1 1/2	1 3/8	1·84	4 1/2
2 1/4	11	6 3/4	1 5/8	1 1/2	1·93	4
2 3/8	11 1/2	7 1/4	1 5/8	1 5/8	2·054	4
2 1/2	12	7 3/4	1 3/4	1 5/8	2·18	4
2 5/8	12 1/2	8 1/4	1 3/4	1 3/4	2·304	4
2 3/4	13	8 3/4	1 7/8	1 3/4	2·384	3 1/2
2 7/8	13 1/2	9 3/4	1 7/8	1 7/8	2·509	3 1/2
3	14	10 3/4	2	2	2·634	3 1/2

Cutting Multiple Threads

The cutting of multiple threads forms an important part of the turner's work. Theoretically, the cutting of these threads is a very simple matter, the calculations and marking being easy, but in practice a considerable amount of experience is necessary before a perfect double, triple, or quadruple thread can be cut.

The usual method adopted for cutting multiple threads is to work out the necessary change wheels to give the required lead, arranging to have a first driver that can be divided into an equal number of parts corresponding with the number of separate threads or starts on the screw to be cut.

The method of procedure is then as follows: One thread is cut nearly to depth, within, say, about three-thousandths of an inch of finished size. The lathe is then brought to the starting position; the first driver is divided into the number of parts corresponding with the number of separate threads. The intermediate or first driven wheel is marked on the two teeth coming on each side of the mark on the first driver. The swing plate is then lowered and the lathe pulled round until the next mark on the driver gears with the two marks on the driven wheel. The next thread is then cut, the operation being repeated until all the threads are cut. It is usual to take a finishing cut for depth down each space, keeping the tool exactly the same depth for each cut.

In cutting multiple threads of such a pitch as to require the marking of the lathe, then the mark on the lathe mandrel must either be altered for each cut, or else numbered 1, 2, 3, etc.

A square thread is not required to fit tightly and accurately all over; it is better practice to cut the grooves slightly deeper than the theoretical depth by about two thousandths, and then rely upon the sides to take up all movement and wear.

In cutting coarse pitch threads when the thread angle is greater than 45°, it is unusual to cut them in the ordinary lathe, as the strain is too great for the change wheels. When they are necessary they should be milled or cut by special machine. In some cases, however, a special arrangement can be attached to the ordinary screw-cutting lathe, by means of which the leading screw itself is driven from the countershaft, and the spindle driven by means of the lead screw.

Cutting Odd Pitch Threads

In cutting certain pitch threads in lathes having lead screws of any pitch, the question of cross threading arises.

If a thread could be cut in one traverse of the tool, no difficulty would ever arise from cross threading, but as most threads require several cuts to complete the screw, it is necessary to know when there is the possibility of not correctly picking up the thread.

When cutting a single-threaded screw having an even number of threads per inch, on a lathe having two threads per inch, the nut can be dropped in at any position without fear of splitting the thread, that is, if the tool is not moved longitudinally after the first cut.

If a screw with an even number of threads per inch is to be cut in a lathe having a lead screw of four threads per inch, then all threads that are an aliquot part of four can be cut without fear of cross threading; these would be 4, 8, 12, 16, 24, etc.

In cutting a single thread with an odd number of threads per inch, on a lathe having a two thread per inch lead screw, the nut can be engaged every ½ in. when the tool is opposite a thread space on the screw, the correct cutting position being on every second revolution of the lead screw.

When cutting screws having an odd number of threads per inch, in lathes fitted with lead screws having an even number of threads per inch, it is always necessary to mark the lathe in order to correctly start the cut.

In cutting fractional threads, such as $1\frac{1}{8}$ thread per in. or $1\frac{1}{8}$ in. pitch, it is necessary in all cases to mark the lathe whatever the pitch of the lead screw.

In cutting multiple threads the question of correctly picking up the cut can be determined by taking each cut separately. Thus a $\frac{1}{2}$-in. pitch screw of 1 in., $1\frac{1}{2}$ in., or 2 in. lead to be cut on a lathe having a $\frac{1}{2}$-in. pitch lead screw, would be done in the same manner as a single thread of 1 in., $1\frac{1}{2}$ in., or 2 in. pitch, and marking up would be required. The same would apply when cutting a $\frac{1}{4}$-in. pitch screw of $\frac{1}{2}$ in., 1 in., or $1\frac{1}{2}$ in. lead on a lathe having a lead screw of four threads per inch.

In cutting double or triple threads on a lathe having a $\frac{1}{2}$-in. pitch lead screw, if the pitch of the former is an aliquot part of the pitch of the lead screw, the driving plate can be marked in such a manner as to correspond with a mark on the lead screw, and successive cuts can be taken according to the number of marks on the driving plate. For example, if a triple thread were being cut, the driving plate would be divided into three equal parts, and the carriage nut could be dropped in when any of these marks corresponded with the mark made on the lead screw.

Marking the Lathe

For Cutting Odd Pitch Threads

When it is not possible to cut a screw without fear of cross threading, it is necessary to mark certain parts of the lathe, the object of this marking being to ensure commencing the nut in identically the same position on every occasion.

To mark the lathe, first have the tool set correctly in the tool holder; second, mark the position of the saddle in some manner to suit the work (by bringing it up against the loose headstock, or up to a piece of wood laid on the lathe bed); third, pull the lathe round until the nut will drop on to the lead screw quite freely; fourth, make a mark on the driving plate or lathe spindle and also one on the lead screw in a similar position. The lathe, on adjusting the tool for depth of cut, will be ready for running. After the first cut has been taken, stop the lathe and bring the saddle back to the starting position, pull the lathe round until all the marks agree, and it is then ready for another cut.

Left-Hand Threads

When cutting a right-handed thread the saddle travels towards the fast headstock; when cutting a left-hand thread it travels in a reverse direction towards the loose headstock.

In order to travel in either direction, and thereby cut right or left handed threads, a tumbler gear is generally provided in the large majority of lathes. By means of this device the motion of the lead screw can be reversed or even disengaged instantly. This gear is illustrated in Fig. 100.

On lathes that are not fitted with some form of reversing gear, when it is necessary to cut left-hand threads, the gear wheels can be arranged to reverse the motion of the lead screw. When a simple train of wheels only are required, then an extra wheel is placed in the train as shown in Fig. 134. The size of this wheel is of no consequence, and therefore any wheel that will gear up can be

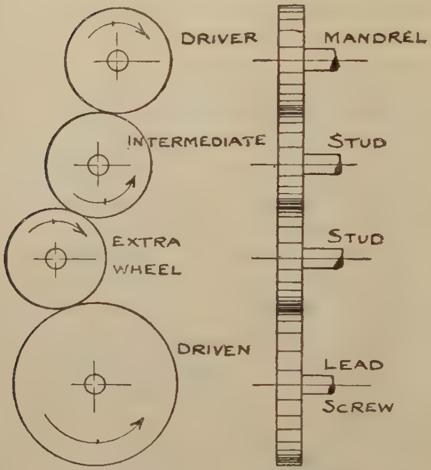


FIG. 134.—Simple Train for Left-Hand Thread.

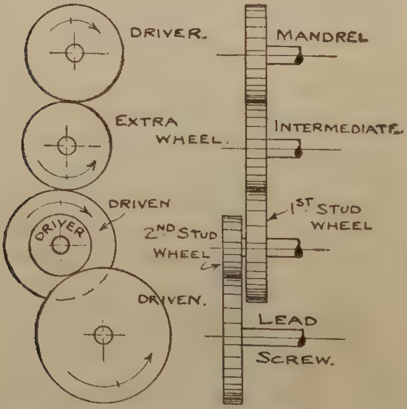


FIG. 135.—Compound Train for Left-Hand Thread.

used. A similar arrangement is needed with a compound train, and in this case the size of wheel has no influence over the ratio, and any wheel can be used that will gear up. This arrangement is illustrated in Fig. 135.

Cutting Speeds

No definite rule can be laid down for the cutting speeds of various threads, so much depending upon the size and pitch of the thread, the nature of the metal, and the skill of the turner.

In cutting fine threads on brass a high speed is desirable; in cutting gas or fine threads on iron or mild steel, the ordinary cutting speed of the metal should be approached as near as possible.

With square threads a speed considerably slower than the ordinary cutting speed of the metal is necessary; with very coarse pitch or large diameter work it is almost impossible to drive too slowly on the average general lathe.

Internal Threads

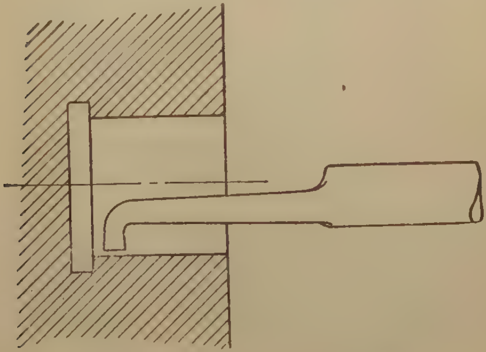


FIG. 136.—Internal Screw Cutting.

When it is necessary to cut internal threads in blind holes, or where it is not possible to run the tool right through the hole, it is necessary to bore a recess at the bottom of the hole as shown in Fig. 136. This hole is bored to the same diameter as the outside of the thread, and slightly wider than the groove in the thread.

Screw-Cutting Tools

Tools for cutting threads in the screw-cutting lathe may be classified according to whether they are to be used for cutting

Internal threads,
External threads;

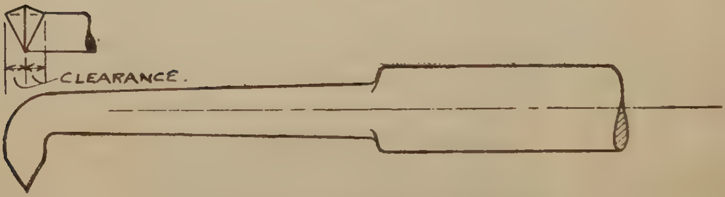


FIG. 137.—Internal Screw-Cutting Tool.

and also whether they are to cut

Vee-shaped threads,
Square threads.

For screwing internal work with a vee-shaped thread a tool similar to Fig. 137 will answer in most cases, but when the hole is very small, a round boring bar made to hold a sectional tool as shown in Fig. 138 would perhaps be more suitable.

Before adjusting a tool for internal screwing it must be ground to the correct angle, for which purpose the screw-cutting gauge shown at Fig. 139 can be used. Care must be taken to give the tool sufficient clearance so that the cutting edge is the most prominent part when the tool is set in the tool holder. This clearance is shown in Fig. 112 and depends on the size of the hole.

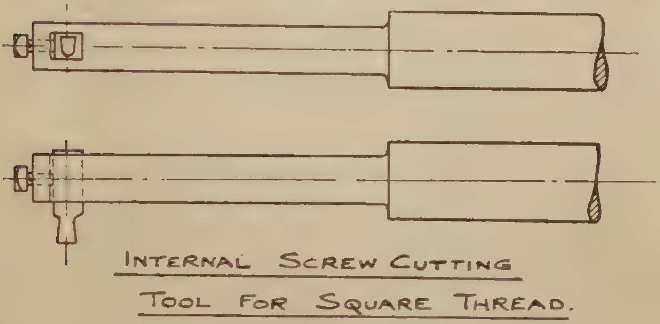


FIG. 138.—Boring Bar.

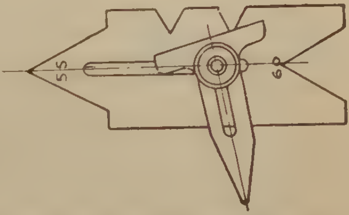


FIG. 139.—Screw-Cutting Gauge.

Rake.—When hard steel or brass is being screwed no top rake is required, but for wrought iron or mild steel a small amount of top rake will improve the cutting action of the tool.

Setting the Tool.—The correct height for all vee-thread boring tools is when the cutting edge is level with the lathe centres. To set the tool square with the work a screw-cutting gauge can be used as shown in Fig. 141 or Fig. 142.

Testing the Thread.—Internal work screwed in the lathe cannot as a rule be removed for testing purposes, and therefore if the actual screw cannot be used to test for depth, then a gauge must be provided. The most satisfactory way to screw threads to the exact depth is to slightly counterbore the hole, say about $\frac{1}{32}$ of an inch, and bore this small depth to a diameter equal to the outside diameter of the screw.

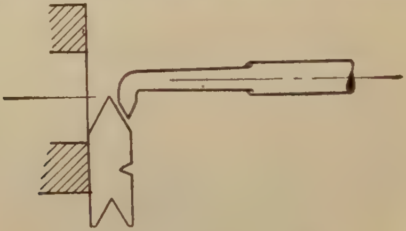


FIG. 141.—Setting Screw-Cutting Tool.

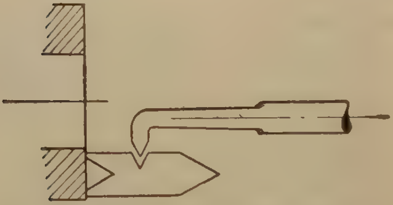


FIG. 142.—Setting Screw-Cutting Tool.

When screwing gas or Whitworth threads the tops and bottoms of the thread can be rounded off with an inside chaser, and when approaching the correct size the screw or gauge should be frequently tried in the hole to ensure a good fit. When testing great care must be taken to see that the first thread is not thicker than the rest, because on the commencement of a cut the tendency is for the tool to be pushed away from the work, owing to only one side of the tool cutting.

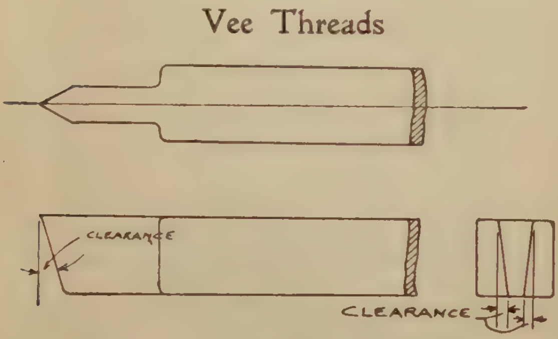


FIG. 143.—Screw-Cutting Tool Vee Threads.

A common form of vee-thread tool is illustrated at Fig. 143, and when grinding to shape it is usual to give about 15° clearance, slightly round the point, and on soft metals give a small amount of top rake. The necessary side rake or inclination necessary to suit the pitch of the thread is given to the tool when grinding it, or if a round section tool is used the tool can be twisted to the required angle. This angle is often judged by the turner, but if large bolts are being threaded the angle can be found and the tool set, as shown in Fig. 144. The circumference of the work and the pitch being marked off, a diagonal line will give the rake the tool must be set to.

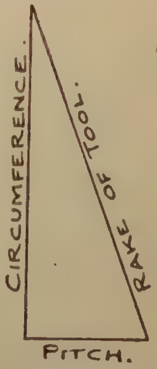


FIG. 144
Inclination of Tool

To set the tool square with the work and ready for screw-cutting operation, the methods shown at Fig. 145 and Fig. 146 can be adopted.

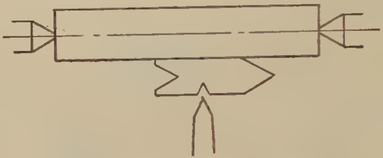


FIG. 145.—Setting Tool.

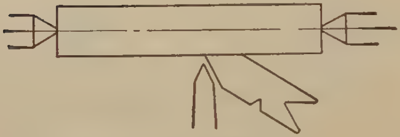


FIG. 146.—Setting Tool.

Square Threads

The most useful form of square-thread screw-cutting tool is made from round section steel, as shown in Fig 147, which can be held in a tool holder similar to Fig. 148. The advantages of this form of tool are: that no

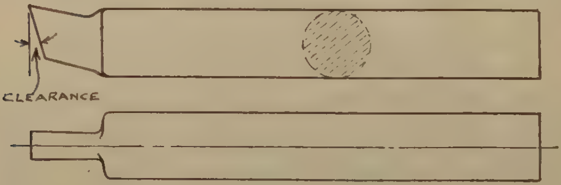


FIG. 147.—Square-Thread Tool.

forging is required; the tool can be ground from the solid bar; it can be set at any inclination, and is easily adjusted.

The correct setting of a tool for cutting multiple threads is most important, the angle or inclination varying both with diameter and lead. Fig. 149 shows the tool angle for threads of two different diameters and various leads. When cutting threads the correct angle should be drawn on paper, and the angle or screw-cutting gauge set to the inclination; the tool can then be set quite accurately.

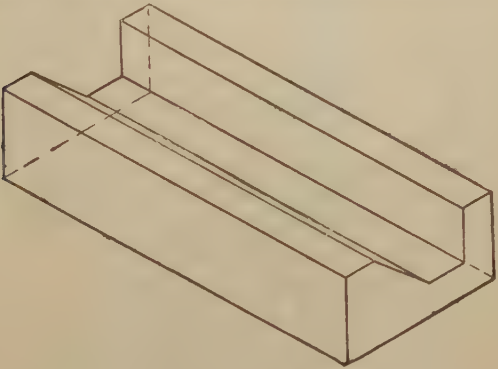


FIG. 148.—Tool Holder.

Position of Screw-Cutting Tools

Fig. 150 illustrates four screw-cutting tools set in different positions. In A the centre of the cutting edge is level with the lathe centre, and the top edge is square with the sides of the thread; this is the correct position. B shows the tool with the bottom corner of the tool level with the centre, and is wrong. C is a common mistake, as it leaves one corner very weak. D is also wrong, as there is a possibility of the tool digging in the metal.

The cutting edges of tools for the majority of threads are

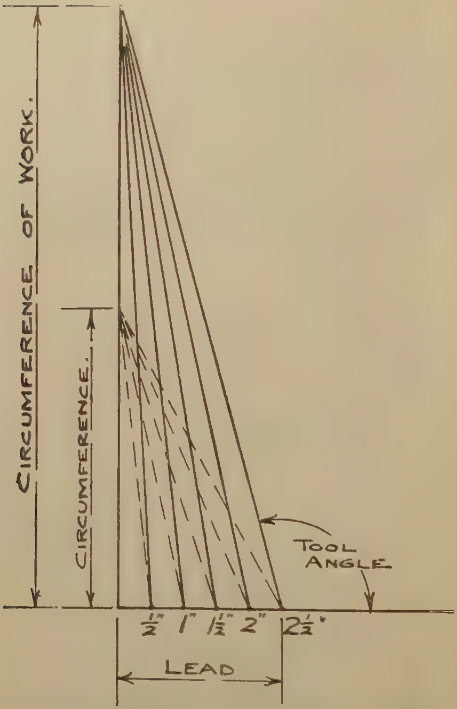


FIG. 149.—Inclination of Screw-Cutting Tools.

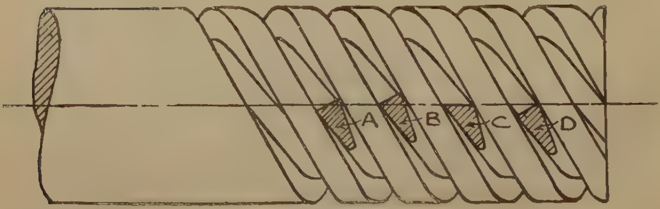


FIG. 150.—Positions of Tools.

ground quite flat, but when threads of long leads are being cut it is necessary to have the cutting edge concave. To obtain this correctly, it should be ground so that it fits against a cylinder of the same diameter at the bottom of the thread when held at the correct inclination for the lead.

When cutting wide threads it is advisable to use two tools, one for roughing out nearly to depth and about half the full width, the other to finish the thread accurately to size. When cutting the full width with one tool it has a tendency to tear the sides of the thread and leave a rough surface. When the thread is started, care must be taken to see the first thread is being cut correctly, as there is a tendency to push the tool away from the thread.

The termination of a thread is of importance owing to the possibility of breaking the tool. Vee-shaped threads can be terminated in a groove turned in the metal without weakening the bolt or screw to any great extent. Square threads can be finished in flat-bottomed holes.

Worm Threads

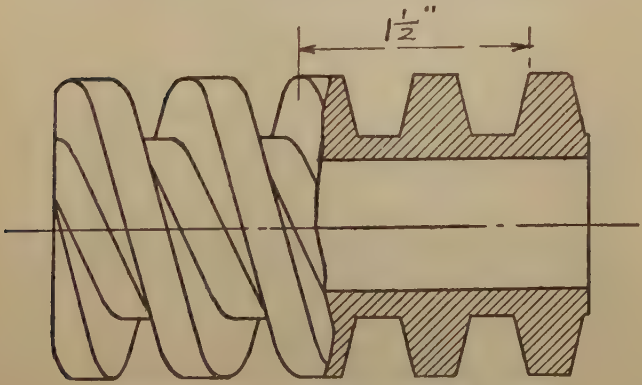


FIG. 151.—Double-Threaded Worm, 1½ in. Lead.

The worm wheel is a wheel having teeth made with short axial pitch, and designed to gear with a worm or endless screw having a long axial pitch. Fig. 151 shows a double-threaded worm of 1½ in. lead.

Worms are made with one or more threads, the form of teeth being in most cases involute, the single curve allowing of easier cutting than double curve teeth.

To cut a worm correctly, especially multiple threads, a hob should be used; this is practically a worm-shaped cutter made slightly larger in diameter than the worm.

Proportions of Worm Threads

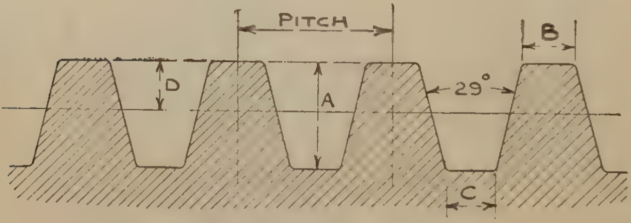


Fig. 152.—Worm Proportions.

The pitch of a worm is the distance from the centre of one thread to the centre of the next, irrespective of its having two or more separate threads. To indicate the distance it would move in a nut in one revolution, the term lead is applied.

Lead = Advance in one revolution.

The proportions of a worm are shown in Fig. 152, the dimensions being—

A = 0.6866 of pitch.
B – 0.335 „
C = 0.31 „
D = 0.3183 „

PROPORTIONS OF WORM THREADS

Circular Pitch (P	Threads per Inch.	Diametral Pitch (DP).	Tooth above Pitch Line.	Working Depth of Tooth.	Clearance (C).	Depth of Space below Pitch Line.	Whole Depth of Tooth.	Thickness of Tooth on Pitch Line.	Width of Thread Tool at End.	Width of Thread at Top.
Inches.	$=\frac{1}{CP}$.	$DP=\frac{3·1416}{CP}$.	$M=\frac{1}{DP}$.	=2M.	$C=\frac{1}{2}(CP$.	=M+C.	=2M+C.	$T=\frac{CP}{2}$.	=·31×P.	=·335 P.
2	$\frac{1}{2}$	1·5708	·6366	1·2732	·1000	·7366	1·3732	1·0000	·6200	·6700
$1\frac{3}{4}$	$\frac{4}{7}$	1·7952	·5570	1·1141	·0875	·6445	1·2015	·8750	·5425	·5862
$1\frac{1}{2}$	$\frac{2}{3}$	2·0944	·4775	·9549	·0750	·5525	1·0299	·7500	·4650	·5025
$1\frac{1}{4}$	$\frac{4}{5}$	2·5133	·3979	·7958	·0625	·4604	·8583	·6250	·3875	·4187
1	1	3·1416	·3183	·6366	·0500	·3683	·6866	·5000	·3100	·3350
$\frac{3}{4}$	$1\frac{1}{3}$	4·1888	·2387	·4775	·0375	·2762	·5150	·3750	·2325	·2512
$\frac{2}{3}$	$1\frac{1}{2}$	4·7124	·2122	·4244	·0333	·2455	·4577	·3333	·2066	·2233
$\frac{1}{2}$	2	6·2832	·1592	·3183	·0250	·1842	·3433	·2500	·1550	·1675
$\frac{2}{5}$	$2\frac{1}{2}$	7·8540	·1273	·2546	·0200	·1473	·2746	·2000	·1240	·1340
$\frac{1}{3}$	3	9·4248	·1061	·2122	·0166	·1227	·2288	·1666	·1033	·1117
$\frac{2}{7}$	$3\frac{1}{2}$	10·9956	·0909	·1819	·0143	·1052	·1962	·1429	·0886	·0957
$\frac{1}{4}$	4	12·5664	·0796	·1591	·0125	·1021	·1716	·1250	·0775	·0838
$\frac{2}{9}$	$4\frac{1}{2}$	14·1372	·0707	·1415	·0111	·0818	·1527	·1111	·0689	·0745
$\frac{1}{5}$	5	15·7080	·0637	·1273	·0100	·0737	·1373	·1000	·0620	·0670
$\frac{1}{6}$	6	18·8496	·0531	·1061	·0083	·0614	·1144	·0833	·0517	·0559
$\frac{1}{7}$	7	21·9911	·0455	·0910	·0071	·0526	·0981	·0714	·0443	·0479
$\frac{1}{8}$	8	25·1327	·0398	·0796	·0062	·0460	·0858	·0625	·0387	·0419
$\frac{1}{9}$	9	28·2743	·0354	·0707	·0055	·0409	·0762	·0555	·0344	·0372
$\frac{1}{10}$	10	31·4159	·0318	·0637	·0050	·0368	·0687	·0500	·0310	·0335
$\frac{1}{12}$	12	37·6992	·0265	·0530	·0041	·0306	·0571	·0416	·0258	·0279
$\frac{1}{14}$	14	43·9824	·0227	·0454	·0035	·0262	·0489	·0357	·0221	·0239
$\frac{1}{16}$	16	50·2655	·0199	·0398	·0031	·0230	·0429	·0312	·0193	·0209
$\frac{1}{18}$	18	56·5488	·0176	·0352	·0027	·0203	·0379	·0277	·0172	·0186

The above table refers to single threads only. For multiple threads divide the thread sizes by the number of threads.

Cutting Worms

When it is required to cut a worm in the lathe, the following method has been found to give excellent results.

The piece of metal is bored to size and driven on a mandrel. It is then turned to the correct diameter and length. The lathe is then set to cut the required pitch as for ordinary screw cutting. A parting, or screw-cutting tool, as shown in Fig. 147, and $\frac{1}{16}$ of an inch narrower than the width of the bottom of the tooth space, is placed in the tool holder and set to the required inclination, and cuts are taken to within $\frac{1}{32}$ in. of finished depth.

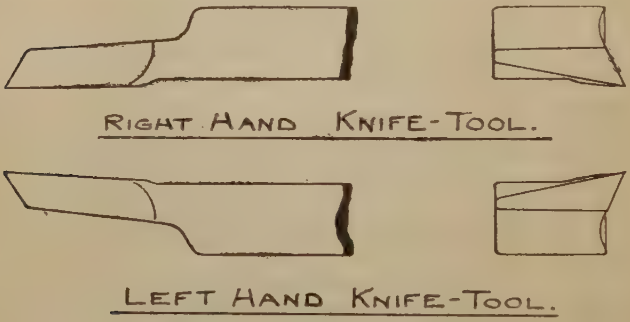


FIG. 153.—Knife Tools.

The slide rest is then set over in either direction $14\frac{1}{2}°$, and one of the knife tools shown in Fig. 153 is put in the tool holder, and cuts are taken to within $\frac{1}{32}$ in. of finished size.

The slide rest is then set over in the opposite direction, and the tools changed. These tools must be carefully ground to the correct inclination suitable for the worm, and ample clearance must be allowed. When the worm is brought to within $\frac{1}{32}$ in. of finished size, it only remains to take finishing cuts, and by means of the tool shown at Fig. 154 this can be done with great accuracy. This finishing tool is best made from round section steel. It should be forged to shape, annealed, filed accurately to size, and then hardened and tempered. Before use it can be sharpened with an oil slip, and then by taking light cuts with a slow speed, and using plenty of lubrication, a well-formed, finely-finished worm can be obtained.

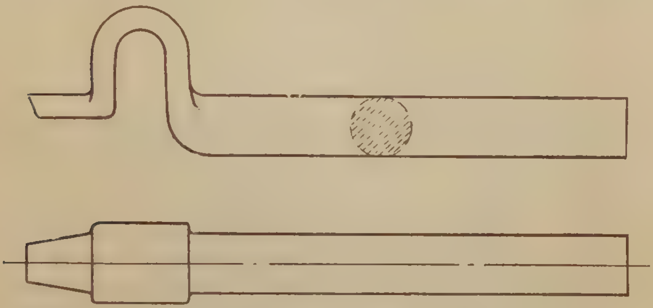


FIG. 154.—Finishing Tool for Worm.

CHAPTER XIII

TRANSMISSION OF POWER

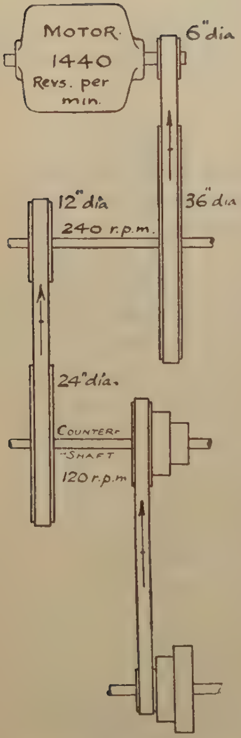


FIG. 155.—Motor Drive.

THE transmission of power in the general workshop is usually provided for by means of shafts, pulleys, and belts, and for that reason it is proposed to deal mainly with that particular method. Before electricity came into general use it was quite usual to erect a line of shafting along the centre or sides of the shop, and drive it by means of one large prime mover. This method is still adopted by some engineering firms. But the more modern shops have the various machine tools driven separately or in groups by means of electric motors. The largest type of machine tools are generally provided with a special motor, in many cases bolted down directly on to the machine bed. The smaller tools have a motor fixed in a convenient place to drive a number of machines in a special group. This last method is illustrated in Fig. 155. Here the motor revolves at 1,440 revolutions per minute, and the speed is reduced to one-sixth of this by running the belt from a 6-in. pulley on to a 36-in. pulley, from whence the belt travels to the machine countershaft, and is further reduced one-half by running from a 12-in. pulley on to a 24-in. pulley, and thus giving a countershaft speed of 120 revolutions per minute. By this means, groups or series of machine tools can be run independent of the remainder of the shop, and therefore, in the event of certain machines not being required, a saving of power might be effected.

Speed of Pulleys

A simple rule for calculating the speed of shafts and the size of pulleys to give a required speed, neglecting any slip of the belt and also the thickness :—

Rule.—Multiply those two numbers together which belong to the same pulley, and divide by the third number ; the result will be the answer required.

The number of revolutions made by connected pulleys are inversely as their diameters. In other words, the diameter of the driving pulley, multiplied by the number of revolutions it makes per minute, is equal to the driven pulley multiplied by the number of revolutions it makes per minute.

Therefore, to find the number of revolutions made by a driven pulley, if the diameter of the driver and driven pulley and also the number of revolutions per minute made by the driver are given—

Multiply the diameter of the driver by the number of revolutions per minute, and divide by the diameter of the driven pulley.

Example.—Diameter of driving pulley, 12 in.; diameter of driven pulley, 6 in. ; number of revolutions made by driver per minute, 120. Find speed of driven shaft. Then—

$$\frac{12 \times 120}{6} = 240.$$

Speed of driven shaft, 240 revolutions per minute.

If the diameter of the driver and the number of revolutions made by the driver and driven pulleys are given. To find the diameter of the driven—

Multiply the diameter of the driver by the number of its revolutions per minute, and divide the result by the number of revolutions made by the driven.

Example.—Diameter of driving pulley, 18 in.; number of revolutions made by driver per minute, 160; number made by driven, 120. Find diameter of driven pulley. Then—

$$\frac{18 \times 160}{120} = 24.$$

Diameter of driven pulley, 24 in.

If the diameter of the driven pulley and the number of revolutions made by both the driven and driving pulley are given. To find the diameter of the driving pulley—

Multiply the diameter of the driven pulley by the number of its revolutions, and divide by the revolutions per minute of the driver.

Example.—Number of revolutions per minute made by the driving pulley, 60; number made by driven, 120; diameter of driven pulley, 20 in. Find diameter of the driving pulley. Then—

$$\frac{20 \times 120}{60} = 40.$$

Diameter of driving pulley, 40 in.

Train of Pulleys

When a train of pulleys is being used, or a number of shafts connected by means of pulleys and belts, the speed of the last driven shaft can be obtained by multiplying together the diameter of all the driving pulleys and the number of revolutions made per minute by the first driver, and divide the product by the diameters of the driven pulleys. The quotient will be the number of revolutions per minute made by the last driven shaft.

Example.—Fig. 156 shows a train of wheels. A, the first driver, is 24 in. in diameter, and revolves at 60 revolutions per minute, B is 12 in. in diameter, C 36 in., both being on one shaft; D 18 in. and E 30 in., on another shaft; F, 20 in., being the last driver. Find the number of revolutions per minute made by pulley F.

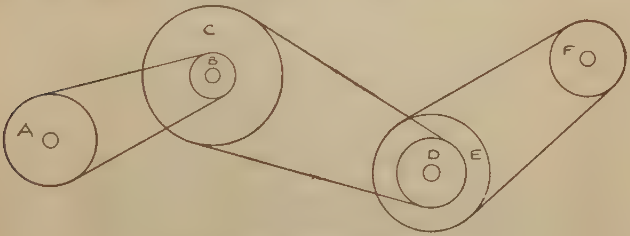


FIG. 156.—Train of Pulleys.

The drivers are A, C, E, and the number of revolutions made by A = 60 per minute.

The driven are B, D, and F. Therefore—

$$\frac{24 \times 36 \times 30 \times 60}{12 \times 18 \times 20} = 360.$$

Revolutions per minute of last driven pulley = 360.

Cone Pulleys

To find the speed of cone pulleys used for altering the speed of machine tools the same method holds good.

Example.—The countershaft of a lathe runs at 120 revolutions per minute, and is fitted with a four-stepped cone speed pulley, having diameters of 6, 8, 10, and 12 in. The speed cone on the lathe mandrel being the same, the various speeds will be—

(1) $$\frac{120 \times 6}{12} = 60.$$

Revolutions per minute, 60.

(2) $$\frac{120 \times 8}{10} = 96.$$

Revolutions per minute, 96.

(3) $$\frac{120 \times 10}{8} = 150.$$

Revolutions per minute, 150.

(4) $$\frac{120 \times 12}{6} = 240.$$

Revolutions per minute, 240

Therefore the speeds that can be obtained are 240, 150, 96, and 60, without taking into consideration any back gear which may be fitted.

Direction of Rotation

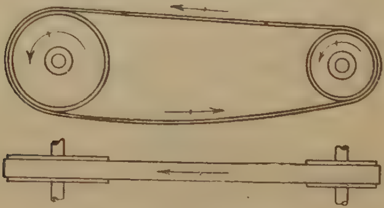


Fig. 157.—Open Drive.

Two methods are available for connecting pulleys, one by means of an open belt, as shown in Fig. 157, by which the driven pulley revolves in the same direction as the driver, and the other by means of a cross belt shown at Fig. 158. Here the belt is tangential to each pulley, and rotates the driven pulley in the opposite direction to the driver.

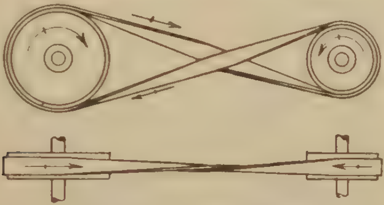


FIG. 158.—Cross Drive.

Problems in Belt Driving

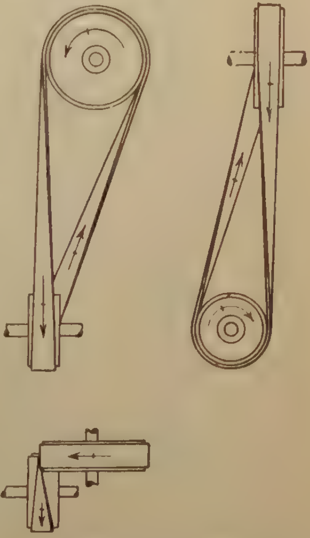


FIG. 159.—Right Angle Drive.

In order to connect two shafts which are at right angles to each other, the method shown at Fig. 159 can be adopted. It is necessary that the point at which the belt leaves either pulley must be in the plane passing the centre of the width of the other pulley, and in all cases must the advancing side of the belt lie at right angles to the shaft.

Fig. 161 illustrates a method of connecting shafts which are neither parallel nor at right angles, and Fig. 160 shows the manner by which two shafts parallel,

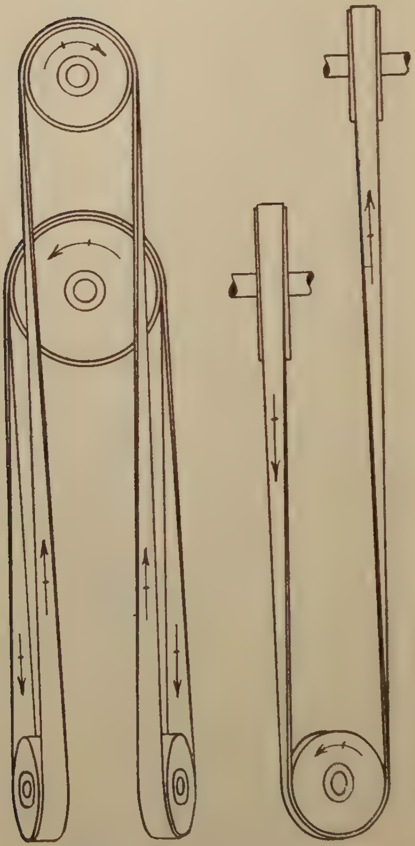


FIG. 160.—Parallel **Drive.**

but at different levels, can be driven. In this case jockey or guide pulleys are required, and the belt is given a quarter twist.

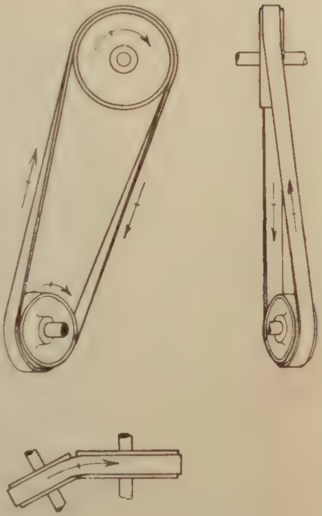


FIG. 161.—Angular Drive.

In arranging the direction of rotation for pulleys, whenever possible it is best to have the slack part of the belt on the top side of the pulleys, as shown in Fig. 162, the tendency being to give a larger arc of contact on both pulleys and to prevent a certain amount of belt slip. Fig. 163 shows the belt arranged to pull in the opposite direction with the slack side of the belt hanging down; this, as can be seen, decreases the arc of contact, causes the belt to slip, and lowers the driving power.

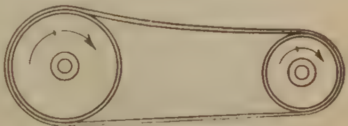


FIG. 162.—Pulley Drives.

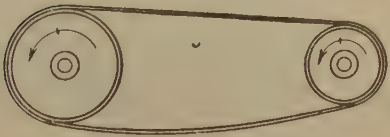


FIG. 163.—Pulley Drives.

When necessity compels the use of a vertical belt drive, the slightest slackness in the belt means slip, and therefore an adjustable jockey pulley is often arranged to take up the slackness, as illustrated in Fig. 164.

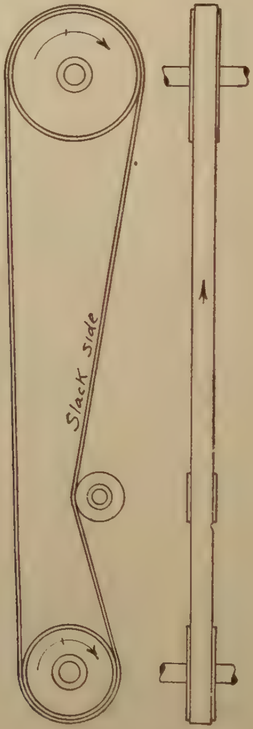


FIG. 164.—Vertical Drive.

Notes on Belt Driving

The best belts are made from raw hide, and should be of double thickness. The life of leather belts can be greatly increased by occasional washing in warm water, and by not using resin or other substances of a similar nature to prevent slipping. The best method to preserve belts and prevent slipping is a little tallow applied to the working face; this may, at first, cause further slip, but as the tallow is absorbed the belt will thicken and tighten up on the pulley.

In all cases excessive tight belts must be avoided, as they tend to cause heated bearings and waste of power, and prove a fault has been made in calculating the size.

Pulleys working together, whose ratio are more than 6 to 1, should not be used, owing to the lost arc of contact.

The driving power of a belt can often be increased by superimposing another belt, and thereby making a compound drive.

The average driving speed of main belts is about 3,000 ft. per minute; for general machinery it is about 1,500 ft. per minute.

Rule for finding actual horse power required for any machine driven by belt—

$$\frac{C' \times R \times W''}{1000} = \text{A.H.P.}$$

C = circumference of fast and loose pulleys in feet.
R = revolutions of countershaft per minute.
W = width of belt driving on fast or loose pulley in inches.
1000 = constant.
A.H.P = actual horse power.

HORSE POWER OF SINGLE LEATHER BELTS AT VARIOUS SPEEDS AND WIDTHS

Velocity in Feet per Minute.	Width of Belt in Inches.									
	2	3	4	5	6	7	8	9	10	12
200	·60	·90	1·20	1·50	1·80	2·10	2·40	2·70	3·00	3·60
250	·76	1·14	1·52	1·90	2·28	2·66	3·04	3·42	3·80	4·56
300	·90	1·35	1·80	2·25	2·70	3·15	3·60	4·05	4·50	5·40
350	1·06	1·59	2·12	2·65	3·18	3·71	4·24	4·77	5·30	6·36
400	1·22	1·83	2·44	3·05	3·66	4·27	4·88	5·49	6·10	7·32
450	1·36	2·04	2·72	3·40	4·08	4·76	5·44	6·12	6·80	8·16
500	1·52	2·28	3·04	3·80	4·56	5·32	6·08	6·84	7·60	9·12
550	1·68	2·52	3·36	4·20	5·04	5·88	6·72	7·56	8·40	10·08
600	1·82	2·73	3·64	4·55	5·46	6·37	7·28	8·19	9·10	10·92
650	1·96	2·94	3·92	4·90	5·88	6·86	7·84	8·82	9·80	11·76
700	2·12	3·18	4·24	5·30	6·36	7·42	8·48	9·54	10·60	12·72
750	2·26	3·39	4·52	5·65	6·78	7·91	9·04	10·17	11·30	13·56
800	2·42	3·63	4·84	6·05	7·26	8·47	9·68	10·89	12·10	14·52
850	2·56	3·84	5·12	6·40	7·68	8·96	10·24	11·52	12·8	15·36
900	2·72	4·08	5·44	6·80	8·16	9·52	10·88	12·24	13·60	16·32
950	2·86	4·29	5·72	7·15	8·58	10·01	11·44	12·87	14·30	17·16
1000	3·02	4·53	6·04	7·55	9·06	10·57	12·08	13·59	15·10	18·12
1100	3·34	5·01	6·68	8·35	10·02	11·69	13·36	15·03	16·70	20·04
1200	3·64	5·46	7·28	9·10	10·92	12·74	14·56	16·38	18·20	21·84
1300	3·94	5·91	7·88	9·85	11·82	13·79	15·76	17·73	19·70	23·64
1400	4·24	6·36	8·48	10·60	12·72	14·84	16·96	19·08	21·20	25·44
1500	4·54	6·81	9·08	11·35	13·62	15·89	18·16	20·43	22·70	27·24
1600	4·84	7·26	9·68	12·10	14·52	16·94	19·36	21·78	24·20	29·04
1700	5·16	7·74	10·32	12·90	15·48	18·06	20·64	23·22	25·80	30·96
1800	5·46	8·19	10·92	13·65	16·38	19·11	21·84	24·57	27·30	32·76
1900	5·76	8·64	11·52	14·40	17·28	20·16	23·04	25·92	28·80	34·56
2000	6·06	9·09	12·12	15·15	18·18	21·21	24·24	27·27	30·30	36·36
2250	6·82	10·23	13·64	17·05	20·46	23·87	27·28	30·69	34·10	40·92
2500	7·58	11·37	15·16	18·95	22·74	26·53	30·32	34·11	37·9	45·48
2750	8·30	12·45	16·60	20·75	24·90	29·05	33·20	37·35	41·50	49·80
3000	9·00	13·50	18·00	22·50	27·00	31·50	36·00	40·50	45·00	54·00
3250	9·40	14·10	18·80	23·50	28·20	32·90	37·60	42·30	47·00	56·40
3500	9·80	14·70	19·60	24·50	29·40	34·30	39·20	44·10	49·00	58·80
3750	10·00	15·00	20·00	25·00	30·00	35·00	40·00	45·00	50·00	60·00
4000	10·18	15·27	20·36	25·45	30·54	35·63	40·72	45·81	50·90	61·08
4250	10·16	15·24	20·32	25·40	30·48	35·56	40·64	45·72	50·80	60·96
4500	10·14	15·21	20·28	25·35	30·42	35·49	40·56	45·63	50·70	60·84
4750	9·88	14·82	19·76	24·70	29·64	34·58	39·52	44·46	49·40	59·28
5000	9·64	14·46	19·28	24·10	28·92	33·74	38·56	43·38	48·20	57·84

To Calculate Lengths of Belts

For open drive

Add together the circumference of both driving and driven pulleys, and divide by two. To this result add twice the distance between the centres of the pulleys. If the joint is to be lapped or spliced, add also the amount.

Pulleys

Pulleys are constructed in a large variety of ways, and from a number of different materials. Cast-iron pulleys are the commonest kind, and they may be of various diameters and widths, both split and solid. One of the disadvantages of the cast-iron pulley is its liability to fracture in the arms, owing to the stress that is set up during cooling in the casting process. In order to prevent this stress the arms of cast-iron pulleys are frequently curved. The straight arm pulley is illustrated in Fig. 165. In this type of pulley a key and keyway is used to

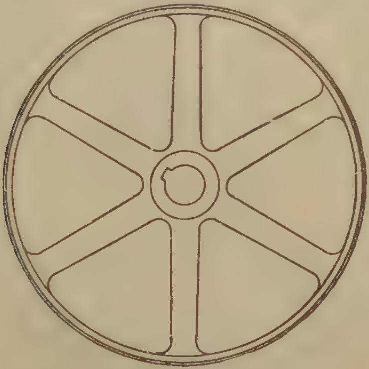


Fig. 165.—Straight Arm Pulley.

prevent the pulley twisting on the shaft; this pulley, which is solid, has many disadvantages, the chief of them being the trouble that must be taken to place the pulley on the shaft, owing to the removal of couplings and possibly other pulleys, and the time taken to effect the same. At Fig. 166 is shown the split form of pulley with curved arms, and in order to fix this to a shaft it is simply necessary to slack out the bolts, and place the two halves together on the shaft and bolt up: if considered necessary, a key can be fitted. Another useful form of pulley is that in which the boss or hub of the pulley is bored out and screwed to a standard size in order to take the screwed bush shown in Fig. 167; by having bushes bored to different sizes the same pulley could be fitted to shafts of different diameters. The inner face of the bush is lined with emery cloth, and being turned and screwed taper on

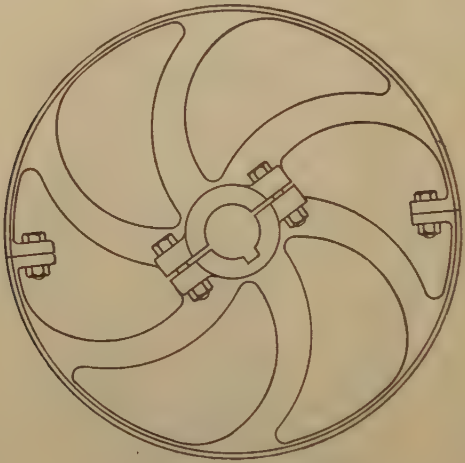


FIG. 166.—Split Pulley.

the outside, the more the belt pulls on the pulley the tighter the bush grips the shaft. With this type of pulley no key or keyway is required.

Large pulleys that are to be run at high speed should be accurately balanced before being used, and great care should be taken to see that the keys are properly fitted. With the larger size of pulley it is usual to fit two keys at right angles to each other. Small pulleys are frequently secured to the shaft by means of a set screw.

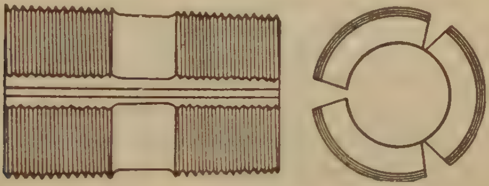


FIG. 167.—Screwed Bush.

Wrought-Iron Pulleys

Wrought-iron pulleys have several advantages over the cast pulley. They are considerably lighter, and therefore less power is required to drive them, they are better balanced, of more uniform thickness in the rims, and are better able to resist the tensional strain.

Wood Pulleys

Pulleys constructed entirely from wood have some advantages; chief amongst them is their lightness, with the consequent reduction of friction in the shaft bearings. They are generally built up in two halves, held together by bolts, and then bored to fit the shaft. For light drives wood pulleys have been found to do the work admirably.

Shafting

The stresses to which power shafting is mainly subject are mostly torsion and bending. The torsional strength or resistance to twisting is proportional to the cube of the diameter, and if the shafting is taken simply as transmitting power its torsional stiffness must be considered as well. The torsional stiffness which determines the angle through which the shaft is twisted varies directly as the fourth power of the diameter, and inversely as the length.

The resistance to bending as a beam is directly proportional to the cube of the diameter, and inversely proportional to the length between bearings.

The transverse stiffness which determines the deflection of a shaft, considered as a beam, is directly proportional to the fourth power of the diameter, and is inversely proportional to the load and to the cube of the distance between the bearings.

The best class of shafting is made from mild steel that has been hot rolled or hammered from best homogeneous bars. Shafting is sometimes produced by a cold rolled process. This method has the disadvantage of sometimes causing crystallisation of the shaft surface, and also leaving a soft centre, with resulting internal strain.

Formula for the Horse Power which Mild Steel Shafts of Good Quality will Transmit at Various Speeds

For line shafts well supported, from which power is taken at intervals along its length, as in the general machine shop—

> Multiply the cube of the diameter of the shaft by the revolutions per minute, and divide the product by the constant, $66\frac{2}{3}$.

For head shafts—

> Multiply the cube of the diameter of the shaft by the revolutions per minute, and divide the product by the constant, 100.

For transmission shafts well supported in bearings, for transmitting power only, and not subject to any transverse strain, also for countershafts supported at short centres and where the pull of belts comes close to bearings—

> Multiply the cube of the diameter of the shaft by the revolutions per minute, and divide the product by the constant, 50.

TABLE OF DIAMETERS, CUBES OF DIAMETERS, AND HORSE POWERS AT ONE REVOLUTION PER MINUTE

Shaft Diameters in Inches.	Cubes of Diameters.	Head Shafts—H.P. per Rev.	Line Shafts—H.P. per Rev.	Transmission Shafts—H.P. per Rev.
1½	3·375	·033	·050	·067
1¾	5·36	·053	·083	·107
2	8	·080	·120	·160
2¼	11·39	·113	·170	·227
2½	15·62	·156	·234	·312
2¾	20·79	·207	·311	·415
3	27	·270	·405	·540
3¼	34·32	·343	·514	·686
3½	42·87	·428	·643	·857
3¾	52·73	·527	·791	1·054
4	64	·640	·960	1·280
4¼	76·76	·767	1·151	1·535
4½	91·12	·911	1·366	1·822
4¾	107·17	1·071	1·607	2·143
5	125	1·250	1·875	2·500
5½	166·37	1·663	2·495	3·327
6	216	2·160	3·240	4·320
6½	274·62	2·746	4·119	5·492
7	343	3·430	5·145	6·860
7½	421·87	4·218	6·328	8·437
8	512	5·120	7·680	10·24
8½	614·12	6·141	9·211	12·282
9	729	7·290	10·935	14·58
9½	857·37	8·573	12·860	17·147
10	1000	10·00	15·00	20·00
10½	1157·62	11·655	17·482	23·31
11	1331	13·310	19·965	26·62
12	1728	17·280	25·92	34·56

The following table shows the approximate limit of distance apart of centres of bearings for shafts which do not carry pulleys or gears:—

Diameter of Shaft in Inches.	2	2¼	2½	2¾	3	3¼	3½	4	4½	5	5½	6
Revs. per Minute.	Distance from Bearing Centres in Feet.											
100	12	12½	13	13½	14	14½	15	16	17	18	19	20
150	11¾	12	12½	13	13½	14	14½	15½	16½	17½	18½	19½
200	11¼	11½	12	12½	13	13½	13¾	14¾	15¾	16¾	17¾	19
250	10¾	11	11½	12	12¼	12¾	13¼	14	15	16	17	18
300	10	10¼	10¾	11	11½	12	12½	13¼	14	15	16	17
350	9¼	9½	10	10½	10¾	11	11½	12¼	13	13¾	14¾	16
400	8½	9	9¼	9½	10	10¼	10½	11¼	12	12½	13¼	14

Table showing distance apart of bearings for shafts carrying an ordinary number of pulleys for transmitting normal power:—

Diameter of Shaft in Inches.	2	2¼	2½	2¾	3	3¼	3½	4	4½	5	5½	6
Revs. per Minute.	Distance of Bearing Centres in Feet.											
100	9	9½	10	10½	11	11½	12	13	14	15	16	17
150	8¾	9¼	9¾	10¼	10¾	11¼	11¾	12¾	13¾	14½	15½	16¾
200	8½	9	9½	10	10½	11	11½	12¼	13¼	14	15	16¼
250	8¼	8¾	9¼	9¾	10	10½	11	11¾	12½	13¼	14¼	15¼
300	8	8½	8¾	9¼	9½	10	10½	11	11¾	12½	13¼	14¼
350	7¾	8	8½	8¾	9	9½	9¾	10¼	11	11½	12¼	13
400	7½	7¾	8	8¼	8½	8¾	9	9½	10	10½	11	11½

WEIGHT OF WROUGHT-IRON SHAFTING TURNED

Diameter of Shaft.	Weight per Foot.	Diameter of Shaft.	Weight per Foot.	Diameter of Shaft.	Weight per Foot.
In.	Lbs.	In.	Lbs.	In.	Lbs.
1	2·62	3¾	33·5	8	168·0
1¼	4·09	4	41·9	8½	189·0
1½	5·89	4¼	47·3	9	212·0
1¾	8·02	4½	53·0	9½	236·0
2	10·5	4¾	59·1	10	262·0
2¼	13·3	5	65·5	10½	289·0
2½	16·4	5½	79·2	11	317·0
2¾	19·8	6	94·2	11½	347·0
3	23·6	6½	111·0	12	377·0
3¼	27·7	7	128·0	14	462·0
3½	32·1	7½	147·0		

The weight of steel shafting may be found by multiplying the above weights by 1.02, the difference being about 13 oz. in 2 ft. of 3-in. shafting.

Bearings

Shaft bearings are made in innumerable shapes and designs. The standard type of plummer block is shown in Fig. 168. In this type of bearing the brasses can be made any length to suit the load, and can be fitted with drop, feed, or grease lubricators. The same type of

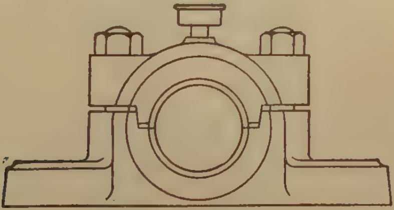


FIG. 168.—Plummer Block.

bearing, arranged so that it can be secured to a vertical column or support, is shown at Fig. 169. Where the line of shafting has to pass through a wall, a wall box similar to Fig. 170 can be used to hold the plummer block. This form of wall box can be firmly bricked in, and forms a good support for whatever type of bearing it is decided to use. The standard type of bearing is not used to any great extent at the present time. It has been displaced by the swivelling bearing shown in Figs. 171 and 172.

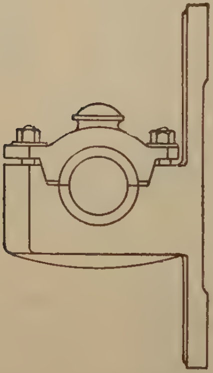


FIG. 169.—Vertical Bracket.

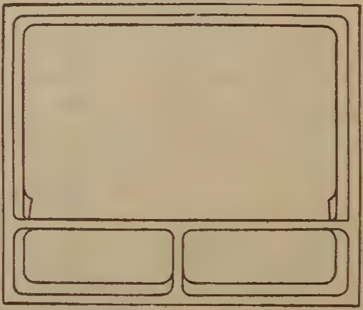


FIG. 170.—Wall Box.

These bearings can be fitted with either cast-iron or white metal-lined bearings, and the swivelling action allows the bearing to accommodate itself to any slight out of alignment of the shaft.

In cases where the pull of the belt is continuously in a downward direction, a top brass is sometimes omitted from a bearing altogether, and a bottom brass only fitted.

A form of "J" or hanging bearing is illustrated in Fig. 173. This type of hanger is used for suspending shafts from roofs or girders, and is sometimes made so that it can be fitted with any form of plummer block or swivelling bearing.

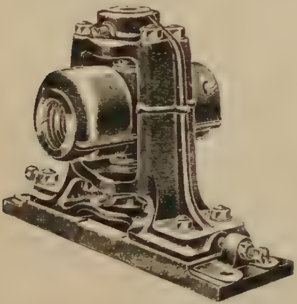


FIG. 171.—Swivel Bearing.

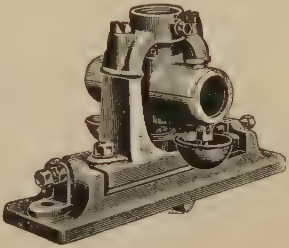


FIG. 172.—Swivel Bearing.

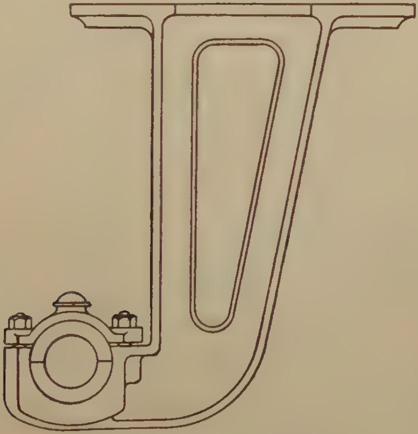


FIG. 173.—"J" Hanger.

Metal for Bearings.—Modern methods of producing shafting, under conditions which result in a straight and perfectly true shaft, allow of bearings to be made of cast iron. This form of bearing, at moderate speeds, has given excellent results, and for ordinary line shafting cannot be excelled. On high-speed work it is not advisable to use cast iron. An alloy of tin, antimony, and copper is considered safer: ninety parts of tin, eight of antimony, and two of copper is an alloy that has given good results on high-speed work. With a cast-iron bearing, should the proper lubrication fail in any way, there is a possibility of the shaft being badly scored, while, in the case of a white-metal bearing, should it run dry, the metal will accommodate itself to the shaft, and then grind or melt before any great amount of harm is done. It is also possible that should the bearing or shaft have a hard place, a great amount of the total pressure would come on that spot, and thereby cause local heating. With such a case an antifriction metal would lend itself to the condition and give way under the influence of the heat, and if properly lubricated would give no trouble whatever. Another advantage of using antifriction metals is the ease with which a bearing can be renewed or replaced, as owing to the low melting temperature, it is possible to run in bearings when in their working position.

Lubrication of Bearings.—A lubricant is an unctuous body which forms a film between two surfaces, and tends to reduce friction. The lubricant chiefly used for line shaft bearings is a grease made from fatty oils and solidified by means of soda, soap, and other similar substances. For faster running shafts, a light mineral oil is more generally used, or else a pure vegetable or animal oil. Graphite in a pure form when mixed with oil forms a highly efficient lubricant.

Couplings.—The method generally adopted for connecting shafts is shown in Fig. 174. It consists of a flanged coupling, with the flanges either plain or recessed to take the head and nuts of the coupling bolts. Each half is keyed to the shaft, and for the best work, or where the shafts are to run at high speed, the flanges should be turned and faced after they have been fitted.

To obtain a clearance space between any two sections

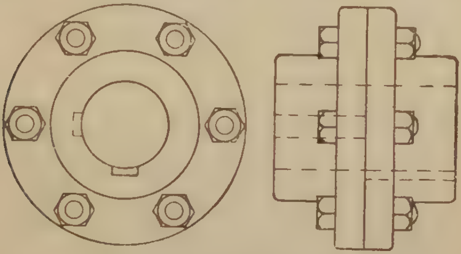


FIG. 174.—Flange Coupling.

of shafting, a distance piece is sometimes fitted between a pair of flanges. This will allow of one shaft to be run without interfering in any way with the other.

Another form of coupling is illustrated in Fig. 175. In this the two halves of the coupling are secured by means of bolts, the two sections of shafts being drawn together, a

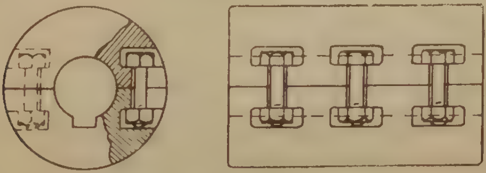


FIG. 175.—Muff Coupling.

key being fitted to prevent the coupling twisting on the shafts.

Worm and Bevel Gearing

Worm and bevel gearing is used to a considerable extent for transmitting power and motion in machine tools.

A worm and worm wheel are used to connect and transmit motion to two non-intersecting shafts set at right angles to each other. A worm is a short length of screw with a specially designed form of thread which gears with a worm wheel, the teeth of which are cut in the rim at an angle corresponding with the inclination of the thread of the worm.

With an arrangement of this description it is made impossible for the worm to move in the direction of its axis, and therefore when it is revolved the worm wheel is rotated, but at a reduced speed. The teeth of the worm wheel if correctly shaped should have a contact with the worm wheel along the entire width.

Worms may have single or multiple threads. A worm having a single thread and gearing into a worm wheel having N number of teeth, would, in one revolution, move the worm wheel a distance equal to $\frac{1}{N}$ part of a revolution.

To move the worm wheel a complete revolution, the worm would have to turn $\frac{N}{1}$ number of times. If the worm had a double thread, then each complete revolution would move the worm wheel $\frac{2}{N}$ part of a revolution, and it would take $\frac{N}{2}$ turns to move the worm wheel a complete turn.

If the worm was triple threaded the number of revolutions it would have to make to move the worm wheel a complete turn would be $\frac{N}{3}$, or one-third the number of teeth in the worm wheel.

Example.—With a worm wheel having 60 teeth, a single threaded worm would have to revolve 60 times to turn the worm wheel one complete revolution; a double-threaded worm would have to make 30 turns, and a triple 20.

Bevel Gearing

Bevel gearing is used to transmit power and motion between two shafts whose axes are at right angles. The velocity ratio when transmitting motion by means of bevel wheels is exactly the same as for spur wheels or pulleys; that is, the revolutions are inversely as the numbers of teeth in the wheels, or as the diameters of the pitch circles.

Speeds and Feeds of Machine Tools

In order to illustrate the use of worms, worm wheels, and bevels for connecting shafts, an example is taken from a very common type of drilling machine, Fig. 176. The power for driving is taken from a countershaft on to the cone pulley keyed to shaft A, which transmits the power to the drill spindle through the two bevel wheels B B.

Feed Gear

The motion for the automatic feed is taken from driving shaft A, and transmitted to shaft C by means of cone pulleys and a belt. From shaft B it is transferred to the vertical feed shaft S by means of the worm W and the worm wheel E. At the top end of the vertical feed shaft a worm W is keyed. This worm gears with the worm wheel F, which in turn moves the rack pinion P, which engages with the drill spindle rack R.

A. Driving shaft.
B. Bevel wheels with 18 and 32 teeth.
C. Feed shaft.
D.S. Drill spindle.
W, W_1. Worms single threaded.
E. Worm wheel with 56 teeth.
F. Worm wheel with 40 teeth.
S. Vertical feed shaft.
P. Rack pinion with 12 teeth.
R. Spindle rack, ½ in. pitch.
H. Hand wheel. Feed cones—maximum, 6 in.; minimum, 3 in.

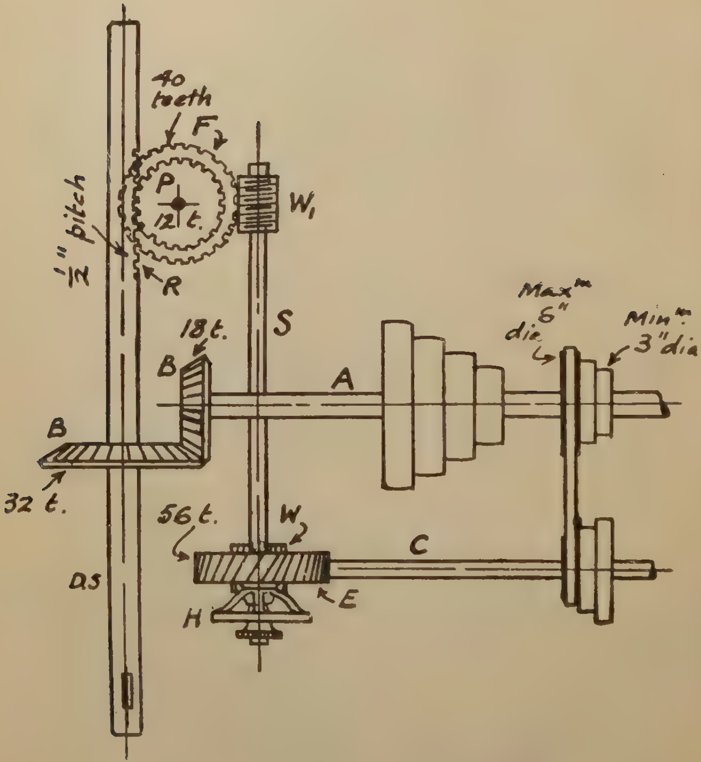


FIG. 176.—Feed Gear of Drilling Machine

Feed Calculations

Example.—From the above data find minimum and maximum revolutions of the drill spindle to give 1 in. of vertical feed.

MINIMUM REVOLUTIONS OF DRILL SPINDLE FOR 1 IN. OF FEED

For each revolution of the drill spindle D.S. the driving shaft A makes—

$$\frac{32}{18} \text{ revolutions.}$$

For each revolution of the drill spindle D.S. the feed shaft C makes—

$$\frac{32}{18} \times \frac{6}{3} = \frac{32}{9} \text{ revolutions.}$$

For each revolution of the drill spindle D.S. the vertical feed shaft S makes—

$$\frac{32}{9} \times \frac{1}{56} = \frac{4}{63} \text{ revolutions.}$$

For each revolution of the drill spindle D.S. the rack pinion wheel P makes—

$$\frac{4}{63} \times \frac{1}{40} = \frac{1}{630} \text{ revolutions.}$$

Number of teeth in pinion, 12; pitch, ½ in.

$$\therefore \quad \frac{1}{630} \times \frac{1}{2} \times 12 = \frac{1}{105}.$$

Therefore for every 105 revolutions of the drill spindle the vertical feed would be 1 in.

To find the maximum revolutions of the drill spindle to give 1 in. of feed—minimum revolutions of drill spindle, 105; maximum and minimum size of pulleys, 3 and 6 in. Then—

$$\frac{105}{1} \times \frac{6}{3} \times \frac{6}{3} = 420.$$

For every 420 revolutions of drill spindle the feed would be 1 in.

Pawl and Wheel Feeds

The shaping machine shown in Fig. 177 takes its power from a countershaft running at 125 revolutions per minute, by means of a four-cone step pulley. This in turn transmits the power to a driving shaft through the medium of a pinion and spur wheel. The ram and tool holder is driven by means of a slotted link, the length of stroke being determined by the distance the connecting pin is placed away from the centre of the slotted spur wheel.

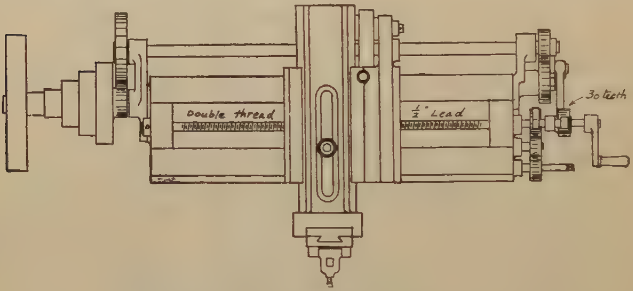


FIG. 177.—Feed of Shaping Machine.

Calculation of Feed

The feed driving wheel is a tee-slotted spur wheel geared to the driving shaft by means of a pinion. A pin is fitted in this slot, and a connecting rod is arranged to move a lever to which a pawl is fitted. The pawl operates a wheel keyed to a double-threaded screw, which moves the carriage. This screw can be moved either by hand or automatically as desired. The maximum amount of feed is obtained by moving the connecting rod pin the greatest distance possible from the centre of the slotted wheel: the angle turned by the pawl lever will then be to its full extent. An enlarged view of the feed gear is illustrated at Fig. 177A.

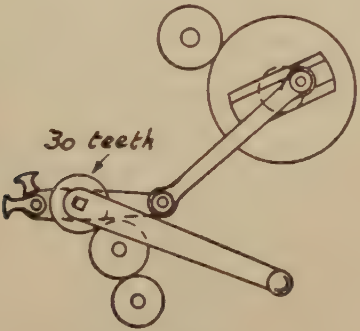


Fig. 177A.—Feed of Shaping Machine.

To Find Minimum Feed

The smallest amount of feed that can be given with a gear of this description will be the amount the carriage moves when the pawl wheel is revolved an amount equal to its teeth pitch.

Example.—With a feed wheel having 30 teeth, and a feed screw of $\frac{1}{2}$ in. lead, find the travel of the carriage if the pawl moves the feed wheel one tooth each stroke.

Then movement of feed $= \frac{1}{30}$ of a turn. Pitch of feed screw, $\frac{1}{2}$ in.

$$\frac{1}{2} \times \frac{1}{30} = \frac{1}{60} \text{ in.}$$

Feed $\frac{1}{60}$ in. per stroke, or 60 strokes per inch of feed.

To Find Maximum Pitch

The maximum amount of feed will depend on the angle turned through by the pawl lever.

Example.—With a feed wheel having 30 teeth, and a feed screw of $\frac{1}{2}$ in. lead, find the travel of the carriage if the pawl lever moves through 60°. The movement of feed wheel, $\frac{60}{360}=\frac{1}{6}$, or 5 teeth. Pitch of feed screw, $\frac{1}{2}$ in.

$$\frac{1}{2}\times\frac{1}{6}=\frac{1}{12}\text{ in.}$$

Feed $\frac{1}{12}$ in. per stroke, or 12 strokes per inch of feed.

CHAPTER XIV

FORGE TOOLS AND PROCESSES

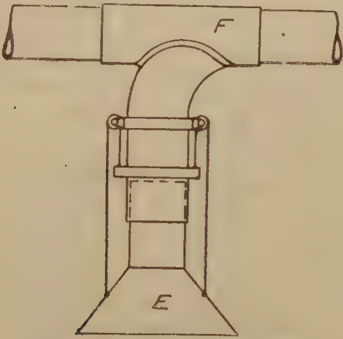


FIG. 178.—Hood for Forge.

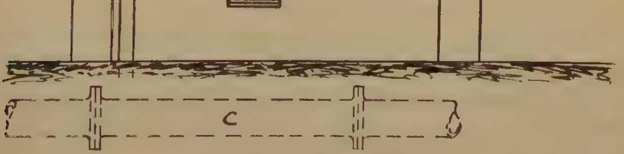


FIG. 179.—Smiths' Forge.

Forging may be termed the shaping of metal while in a hot state by hammering or pressing. The metals chiefly used in forging processes are iron, steel, and alloys of copper and other elements. The term metal is used in a general sense, iron and steel being really compounds. A modern type of forge is illustrated at Figs. 178 and 179, the various parts being A, hearth; B, air chamber; C, main air supply; D, bosh or water tank; E, hood for collecting the smoke (this hood can be raised or lowered as desired); F, the main flue.

The air supply is maintained by means of a blower, and the waste gases are removed by some type of fan placed in the chimney of the flue.

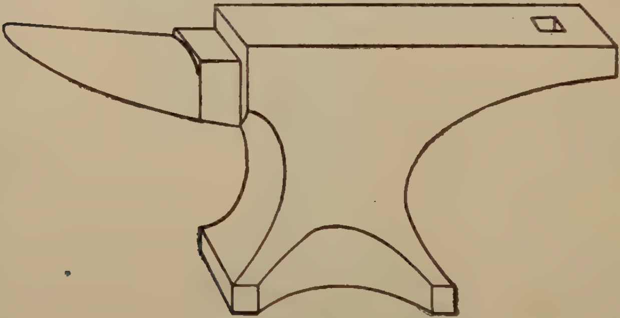


Fig. 180.—Anvil, London Type.

Forges are made in innumerable shapes and sizes, both fixed and portable. Some have a brick hearth, and others are made from cast or wrought iron; those made from iron are generally lined with fireclay or firebricks. A very useful size of forge is one with a hearth 36 in. × 28 in. It is common to fit a tuyere to each forge: this is a cast-iron water-cooled nozzle, through which the air is forced, the water jacket preventing the metal from being burned.

The **Smith's anvil** weighs about 3 cwt., and is made from wrought iron faced with double shear steel about $\frac{3}{4}$ in. thick. The beak is also faced with steel, but the flat portion between the beak and the anvil proper is left soft, in order that hot and cold sets will not be damaged when cutting off work. Fig. 180 shows what is known as the London type of anvil. In the United States cast-iron anvils faced with cast steel are used, and considered superior to the wrought-iron ones, in so much that they retain their shape longer.

To support the anvil a block of hard wood, with the grain running downwards, is laid on a block of concrete; the anvil is then secured by means of iron spikes. Another method of supporting the anvil is to provide a special cast-iron base; in either case the height of the anvil face should be about 22 in.

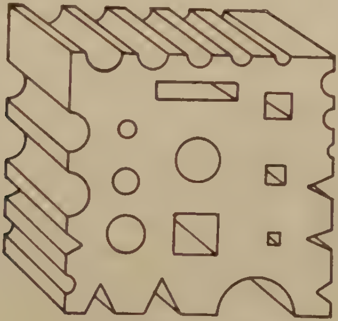


Fig. 181.—Swage Block.

Tools

Swage Block.—Fig. 181 illustrates a swage block. This is an appliance without which a smithy would be incomplete. It is a cast-iron block pierced with holes of various sizes and shapes, the edges being provided with grooves of different sizes in half round and vee-shaped forms. When used lying on its face, it is possible for holes to be punched and drifted, and when on its side the grooves act as bottom swages for round, hexagonal, and rectangular work. The swage block is mounted upon a special cast-iron frame, made to hold it either on its face or edge.

Hammers.—The hammers used in the smithy, excluding the power forms of hammers, are the hand hammer and the sledge. The hand hammer is very similar in shape to the engineer's hammer, but larger and somewhat heavier. The sledge hammer is made in the two forms shown in Figs. 182 and 183. The weight varies between 9 and 16 lbs.; they are used by the smith's hammerman as directed by the smith. The shafts of these hammers should be truly inserted in the heads, and then wedged with a hard wood or twisted iron wedge, the latter being preferred. The smith uses the hand hammer for light work, and indicates the position upon the work at which the blows of the sledge are to fall by tapping with the hand hammer; to stop the blows, he taps the anvil.

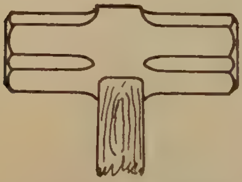


FIG. 182.—Sledge Hammer.

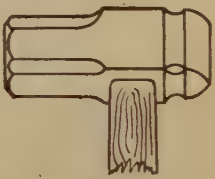


FIG. 183.—Sledge Hammer.

Swages.—These tools are made in a variety of shapes, and are used for many different purposes. Fig. 184 illustrates one form of both top and bottom swage; the bottom tool is held by dropping it in the square hole in the anvil, and the top tool by means of an iron or hazel rod. A form of spring swage is shown in Fig. 185. With this tool a piece of work can be swaged down without the aid of a hammerman.

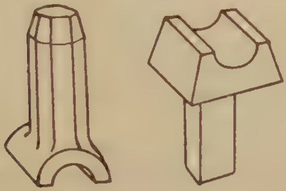


Fig. 184.—Top and Bottom Swages.

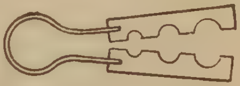


Fig. 185.—Spring Swage.

It is possible, with any form of swage, to shape or draw down a piece of metal much quicker and better than would be possible if the hammer alone were used. Hexagonal work, such as the shaping of bolt heads, the making of nuts, and work of a similar character, is carried out by means of formed swages. Collars are shaped and welded in special collar swages made in suitable sizes.

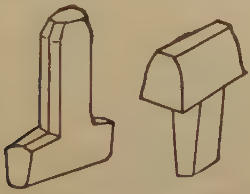


Fig. 186.—Top and Bottom Fullers.

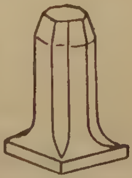


Fig. 187.—Flatter.

Fullers.—Top and bottom fullers are made in the shape shown in Fig. 186, the bottom tool being held in the anvil. These tools are used for a variety of purposes according to their particular shape. In addition to the flat fuller shown, there is a round-faced fuller which is used for spreading stock; and for some welding processes a hollow fullering tool and a half round tool are used.

Flatter.—The flatter is used to flatten work, and to remove hammer or tool marks. It is held by the smith, whilst the hammerman strikes it with the sledge. This form of tool is shown at Fig. 187.

Punches.—Holes are made in iron or steel by driving a punch through the metal. The bar of metal is made hot, and a punch of the desired shape is driven through. The punch may be round, square, oblong, or wedge shape, and is generally made slightly tapered.

Drifts.—Drifts are used to finish holes that have been first drilled or punched smaller than the finished size. They are taper or parallel tools, having round, square, oblong or special cross sections.

Bolsters.—Bolsters are generally used in conjunction with punches and drifts; they consist of pieces of iron of different thicknesses, having holes of various shapes cut in them.

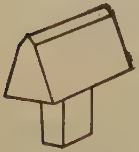


Fig. 188.
Anvil Cutter.

Anvil Cutter.—The form of tool shown in Fig. 188 is termed an anvil cutter. It is held in the square hole of the anvil, and used for cutting off pieces of metal or small work single-handed.

Sets. — For cutting metals a tool known as a set is used. This is a form of chisel held either by means of a wood handle, or by a bent hazel stick. The cold set is thicker and heavier than the hot set, and is used for cutting metal when cold. To cut a bar of iron, the bar is laid on the anvil, and nicks are made on it with the set; when it is marked all round, a few heavy blows on the set will break the bar. The hot set is used for cutting metal when hot, the set is driven in deeply by means of blows from the sledge hammer, the bar of metal being revolved; when nearly through it is then held on the softer part of the anvil and completely severed. Hot sets are usually provided with fitted handles similar to the hand hammer. Rod tools are fitted with handles made from hazel sticks or round iron. To fit the former to a tool, a $\frac{5}{8}$-in. stick about 4 ft long is taken, and about 12 in. of the centre is alternately warmed over the forge, and soaked in water until it is soft; it is hammered and twisted, and can then be bent round the tool. The iron handles are made from round iron, $\frac{3}{8}$ in. diameter: the centre part is made hot and twisted round the tool, the ends being brought together to form a handle, and then welded.

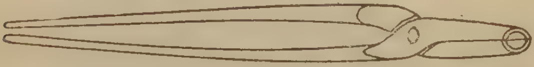


Fig. 189.—Hollow Bit Tongs.

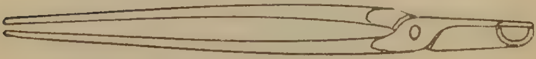


Fig. 190.—Bar Tongs.

Tongs.—Tongs of ordinary size are generally forged from a piece of square section metal. This is drawn down to thickness and width, and twisted to form the shape desired. It is then cut off, leaving sufficient metal to weld on the handles. When both parts of the bit are made, the ends are scarfed and the handles welded on; these are usually made from $\frac{1}{2}$-in. round iron. When this is done, the hole is drilled and the rivet fitted. Fig. 189 shows a pair of hollow bit tongs. These may vary in size between $\frac{1}{4}$ in. and 3 in. Fig. 190 illustrates a form of tongs used for holding pieces of flat bar metal.

Fig. 191 shows a pair of hoop tongs. These are particularly useful for holding rings and work of a similar character. Fig. 192 shows what are called pick-up tongs. The variety and shape of tongs are endless, special work calling for special shaped tools. For holding work, and in order to give freer play to the hands, a ring is made to encircle the handles. This is slipped over the reins, and tightened up with a tap from the hammer.

Measurements.—For taking measurements on work that is being forged, a rough form of caliper, having a long handle, is used. A gap gauge, which is a bar of metal having gaps of various widths, is also a useful tool.

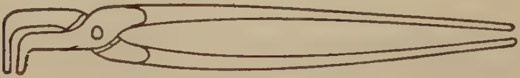


Fig. 191.—Hoop Tongs.

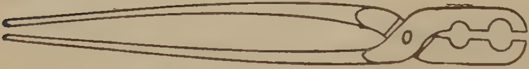


Fig. 192.—Pick-Up Tongs.

Power Hammers.—Hammers to work by some form of power are used to a great extent. Even the small shop, employing quite a few men, finds it economical to have a small power hammer. These tools are made to be worked by means of steam and air pressure, and vary in size and power according to the nature of the work on which they are to be used. Hydraulic pressure is frequently used in producing large stamped or pressed forgings.

Bolt, Rivet, and General Forging Machines

Whenever nuts, bolts, rivets, or small forgings have to be produced in quantities, they are made by means of a special forging machine. In the Hallfalls machine the main frame is made from a heavy casting of sufficient strength to withstand the vibration and shock to which these types of machines are subjected. The bearings for the camshaft are formed in the bed, the thrust being taken by the main frame, and not on the caps. The guides for the closing die, side hammer, and header slides are also formed in the bed.

The cams are made from high-grade chilled cast iron, pressed on and keyed to the camshaft. The cams are lubricated as they revolve from an oil well formed in the bed of the machine. They operate against hardened steel thrust or tail pieces, these latter being adjustable on the intermediate slides, which are in contact with, and operate, the closing die and side hammer slides.

The heated stock is first gripped by the tools carried in the closing die slide, while the two header or bunter tools, and the side hammer tools, operate. The top header tool operates first, breaking the metal down. The second tool forms the work to the desired shape, and the tools carried in the side hammer slides work the metal from the sides. In the case of machines arranged for the production of nuts, the header or bunter slide also carries a punch.

The operation of cutting off is performed at the same heat, and on the same machine, by means of a pair of shear blades located between the main frame and the right-hand side hammer slide.

To relieve the machine of undue strain, caused either by accident or carelessness, a cast-iron breaker is inserted between the frame and the fixed closing die slide. The breaker is made sufficiently strong to withstand the normal working pressure, but gives way immediately any exceptional strain is put on the machine.

These types of machines are generally driven by means of self-contained fast and loose pulleys, or by powerful spur or double helical gearing.

For the purpose of heating the metal a special furnace is provided. This is designed with the object of heating a large number of pieces at one time, and also to allow the metal to be easily withdrawn. They are made for use with coal as a fuel, but the latest type is fired by means of an oil. This is a cleaner and more reliable method.

Output of Forge Machines

The rate of production necessarily varies with the experience of the operator, the class of work, and the heating capacity of the furnace. The following figures, however, may be taken as well within the average rates of production under normal conditions, one man operating the machine, and a boy attending to the furnace.

PRODUCTION PER WEEK OF FIFTY-FOUR HOURS

⅜ in. snap-head bolts with square necks, 120 gross per week.
⅝ ,, ,, ,, ,, 90 ,,
1 ,, ,, ,, ,, 75 ,,
1¼ ,, ,, ,, ,, 70 ,,

⅜ in. hexagon-head bolts with round necks, 80 to 100 gross per week.
⅝ ,, ,, ,, ,, 60 ,, 80 ,,
1 ,, ,, ,, ,, 45 ,, 50 ,,
1¼ ,, ,, ,, ,, 40 ,, 45 ,,

Bolts in small quantities are usually made by the general smith, who uses what is known as an Oliver hammer. All the forming tools are made to fit the anvil, and therefore it is possible for the smith to work without the aid of a hammerman. The hammer is worked by means of a

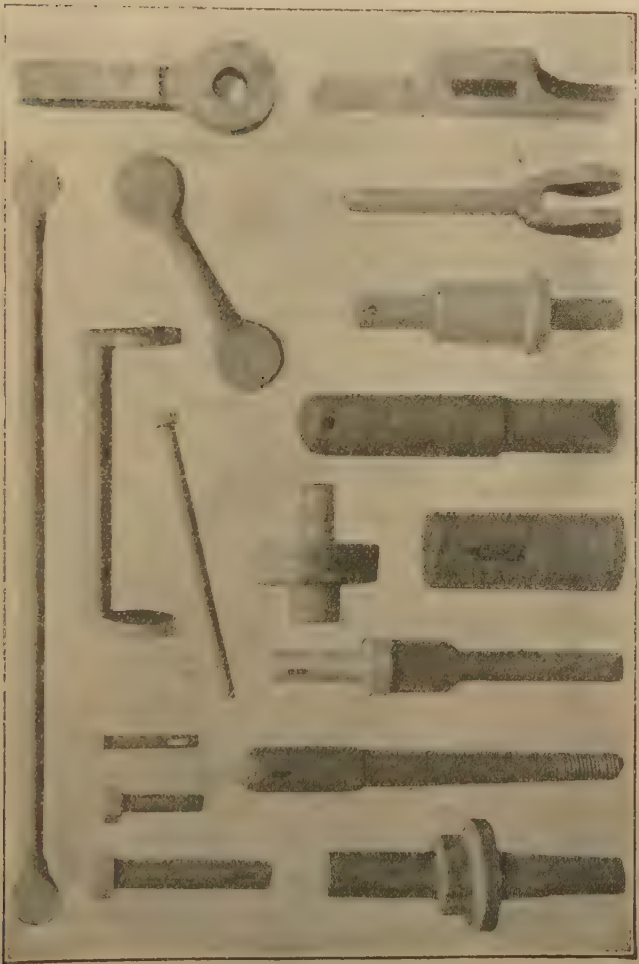


FIG. 193.—Examples of Machine Forge Work.

treadle board, to which one end of a chain is fastened, the other end being fastened to a flexible pole. A short lever is fastened to the chain, this lever being connected to a pivoting boss. When the foot is pressed on the board the hammer descends, and on the release of the foot the flexible pole lifts the hammer ready for another blow.

Machine Forging

When forgings have to be produced in large quantities, the work is generally done by means of the forging machine. The general design of this type of machine has just been described; the work itself is formed by means of various tools and dies, each forging requiring a separate set of dies. Examples of machine forge work are shown in Fig. 193.

Forging Processes

Forging operations consist of upsetting, welding, drawing down, or a combination of those processes. The method to be adopted can only be decided by a consideration of the various sizes and forms required, the sizes of metal in stock, and the relative amount of work required for each different method.

Upsetting

Upsetting is a method of enlarging a piece of metal, and can be adopted as an alternative to drawing down or welding. Fig. 194 shows a bar of metal with a collar or head at one end. To produce this collar by the upsetting method, the end is heated to a white heat, and then, if it is a long bar, it is jumped vertically on the iron block

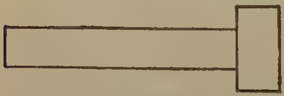


FIG. 194.

fixed in front of the anvil, as in Fig. 195, until sufficient metal is obtained to form the head. If the bar is short, it can be held on the anvil face with a pair of tongs, and hammered with the sledge. Should the bar be very long, the end can be upset by holding the bar horizontal and hammering with the sledge, but in any case only sufficient metal should be heated to produce the size of head required. If too much metal is heated it should be cooled off, but with care the metal can be kept cold by means of wet coal. When sufficient metal is obtained to form the head the shape would be as shown in Fig. 196; it would then be finished to size and shape by the use of suitable swages, or a heading tool, the end being finished with the flatter.

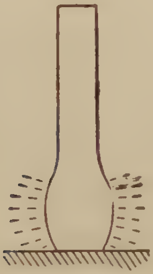


FIG. 195.

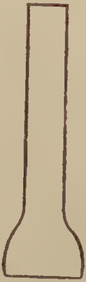


FIG. 196.

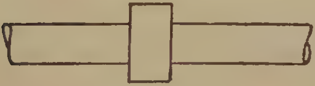


FIG. 197.

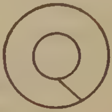


FIG. 198.

A similar method could be adopted to produce a collar in the centre of a shaft, as shown in Fig. 197, that is, by localising the heat, and then upsetting the metal by vertical or horizontal jumping. In cases like these, however, it is generally more expedient to weld a piece of metal in the form of a collar on to the bar. To do this, a bar of metal, about $\frac{1}{8}$ in. larger in section than the finished size, would be prepared, and bent over the beak of the anvil into the form of a ring, Fig. 198. It would then be cut off, leaving sufficient metal to allow for welding, the ends cut diagonally and prepared, flattened on the anvil, and made true to shape on a mandrel, and it would then be ready for welding.

To weld it to the bar, the ring would be placed in position, and the whole part would be heated to a welding temperature. It would be quickly withdrawn from the fire and given a few blows with the hand hammer on the scarf joint and on the circumference of the ring, the shoulders would be finished with swages, and, if of large size, the hollow tool and sledge would be used.

Welding

Welding is a term generally applied to the joining together in union of two pieces of iron or steel when under the influence of heat. The ordinary method of hand welding is as follows: The pieces of metal to be welded are carefully prepared by scarfing and fitting together. They are then brought to a suitable temperature, which for iron is a dazzling white, and for steel a darker white. They are then removed from the source of heat, and union is effected immediately by a few blows from the hand hammer

Welding Heat.—The welding heat necessary for iron and steel differs, and even different qualities of steel require different welding heats. Wrought iron of best quality can be brought to a melting temperature without in any way damaging the nature of the metal, and therefore the iron oxide which forms on its surface can be fused, and during the actual union of the metal it will be pressed out in liquid form.

Mild steel requires a somewhat lower heat than iron, and more care must be taken in bringing it to a welding heat. High carbon and tool steel seldom require welding, although it is possible with great care to do so. The difficulty of successfully welding steel arises chiefly from the presence of the carbon in the steel, and from the fact that two bars of metal may differ slightly in the proportion of carbon they contain. With two bars of steel containing a similar proportion of carbon, the melting points would coincide, and at the welding heat their plasticity would be about equal, therefore, in welding steel, the pieces to be joined should, whenever possible, be taken from the same bar.

Fluxes.—The formation of oxide is the greatest obstacle in the way of successful welding, because it prevents the proper contact being made between the surfaces of the metal being welded. Where the metal cannot be brought to a temperature high enough to fuse the oxide, a flux to facilitate the melting and flowing is sometimes used. The fluxes most used are sand, borax, sal ammoniac, and prussiate of potash. Sand is cheap, and therefore most frequently used; with this, the silica combines with the oxide and forms a ferrous silicate, which is fusible at a temperature which does not injure the steel. Borax melts at a lower temperature, and is used when welding the harder varieties of steel.

Form of Welds

To obtain a good sound weld the metal must be upset, and the scarf should be sufficiently larger than the finished size to permit the weld to be full size when finished. The joints of the scarf should be slightly rounded, so that when they are placed together no air will be enclosed, and the oxide will be able to squeeze out. The ends or joints should be allowed to heat slowly and thoroughly in a clear, bright charcoal fire, and be made as hot as possible without burning.

When withdrawn from the fire a wire brush should be quickly passed over the joints, which should be united immediately the parts are joined together by blows from the hammer. As soon as they are united, blows should be given to close the edges of the weld.

A scarf-joint weld is formed by upsetting the ends of the metal and then scarfing them; this is done by first cutting the ends square and then jumping them up with the sledge hammer, and spreading them out with a fullering tool, the result being a slightly rounded joint, as in Fig. 199. Both ends are treated in the same manner, and are then placed in the fire and brought to a welding heat; they are then laid together, and if both pieces have an equal and correct temperature, they can be united with a few blows from the hammer.

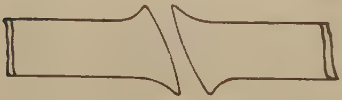


FIG. 199.—Scarf Weld.

Another form of weld is the tongue joint, shown at Fig. 200. With this form of weld the ends are first upset, the fork end being prepared by slitting the end of the metal with the hot set, and opening it out to form the

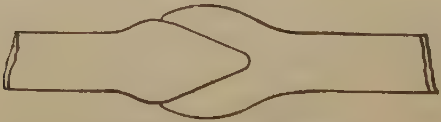


FIG. 200.—Tongue Weld.

wedge-shaped slot. For the tongue piece the fuller is used on opposite sides of the metal, and it is then drawn down to fit right to the root of the wedge slot. To ensure a good sound weld a blow is first given to the end of the tongue piece, thus jumping it right down to the root of the slot.

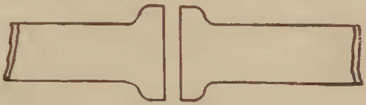


FIG. 201.—Butt Weld.

The butt joint shown at Fig. 201 is prepared by jumping up the ends of the metal and slightly rounding the faces.

Drawing Down

To draw down a bar of metal, it is usual to first mark the bar with the fuller, and then draw it down with the sledge, finishing it with top and bottom swages, or the flatter, as may be required. When both sides of a piece of work are to be drawn down, a bottom fuller would be used at the same time as the top one. To draw down a round or flat bar, as shown in Fig. 202, a bottom fuller would be placed in the anvil, the bar would be heated and laid on the fuller, and with a top fuller the notches shown in Fig. 203 would be made. The end would be hammered with the sledge to shape, and finished with the flatter.

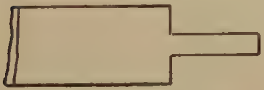


FIG. 202.—Drawing Down.

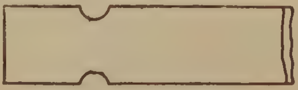


FIG. 203.—Fullering.

Forming a Link

In forming a chain link, a rod or bar of metal is bent to form a U; it is then cut off to length, the ends being laid over diagonally with the hammer, as shown in Fig. 204, and bent to shape on the beak of the anvil. The faces are then brought together ready for welding, which can be done on the anvil beak, or with the aid of a special linking forging tool: this tool is held in the anvil, and is provided with a hook for holding the link. To finish off the welded link a hollow swage tool is generally used.

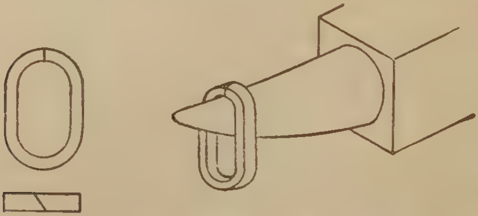


Fig. 204.—Making a Chain Link.

Fork End

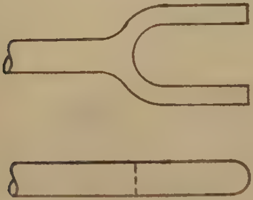


Fig. 205.—Fork End.

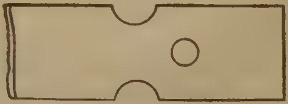


Fig. 206.—Fullering.

To produce a fork end, as shown in Fig. 205, a bar of metal is fullered down as in Fig. 206, a hole is then punched and the metal slit with the hot set, as in Fig. 207. It is then opened out as in Fig. 208, and forged to shape by bending, cutting, and hammering.

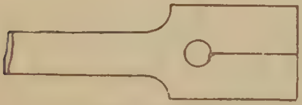


FIG. 207.
Drilling and Slitting.

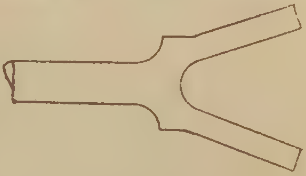


FIG. 208.
Opening Out and Shaping.

Crankshafts

In the making of a small crankshaft the greater part of the work is done by machine. A steel bloom is taken and planed on both sides, holes are then drilled and pieces are cut out by means of power saws to form the webs. The whole piece is then heated in a special furnace, and the cranks twisted to the correct angle in a specially

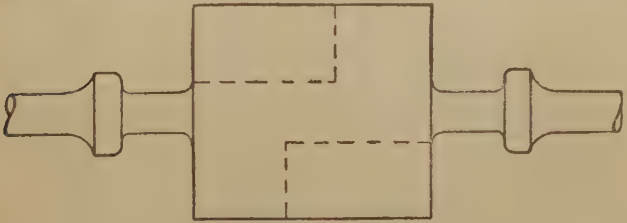


FIG. 209.—Forging a Crankshaft.

constructed machine; it is then turned, and afterwards ground to size. For larger cranks a slab of steel is forged under the power hammer or by means of an hydraulic press to the shape shown in Fig. 209. The parts shown by dotted lines are machined or sawn out, and the cranks thus formed. The shaft is then heated and cranks twisted to the required angle, the surplus metal at the ends is cut

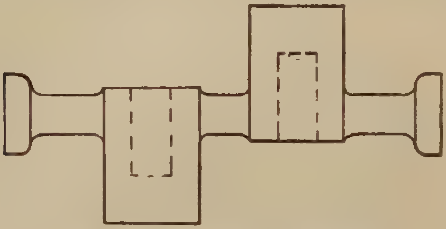


FIG. 210.—Shaping a Crankshaft.

off, and then the part shown with dotted lines in Fig. 210 is drilled and sawn out, and the shaft is ready for the lathe.

CHAPTER XV

TURRET LATHES

THE turret lathe is a labour-saving machine, designed for the purpose of taking the place of the ordinary sliding surfacing and screw-cutting lathe when engaged on repetition work.

It is constructed in an infinite variety of designs and sizes. A modern type specially constructed for bar work is illustrated at Fig. 211. As will be seen, the fast headstock is of the all-geared type, the speed changes being made by means of three easily accessible levers. The height of the spindle centre above the bed is 10½ in., and the bed is of sufficient length to enable pieces 3 ft. long to be turned at one pass. The speed of the driving pulley is 475 revolutions per minute. The spindle is bored out to $3\frac{3}{16}$ in. diameter, enabling bars of 3 in. diameter to be operated upon, the bar chuck being provided with gripping dies.

All the gear wheels in the headstock are of steel, with the exception of the largest spindle wheel. They are hardened and completely enclosed by a cast-iron cover. The clutch controlling the first two changes of speed on the high-speed pulley shaft, which is generally used for starting and stopping the lathe, is of the expanding ring type; the intermediate changes are made by sliding the

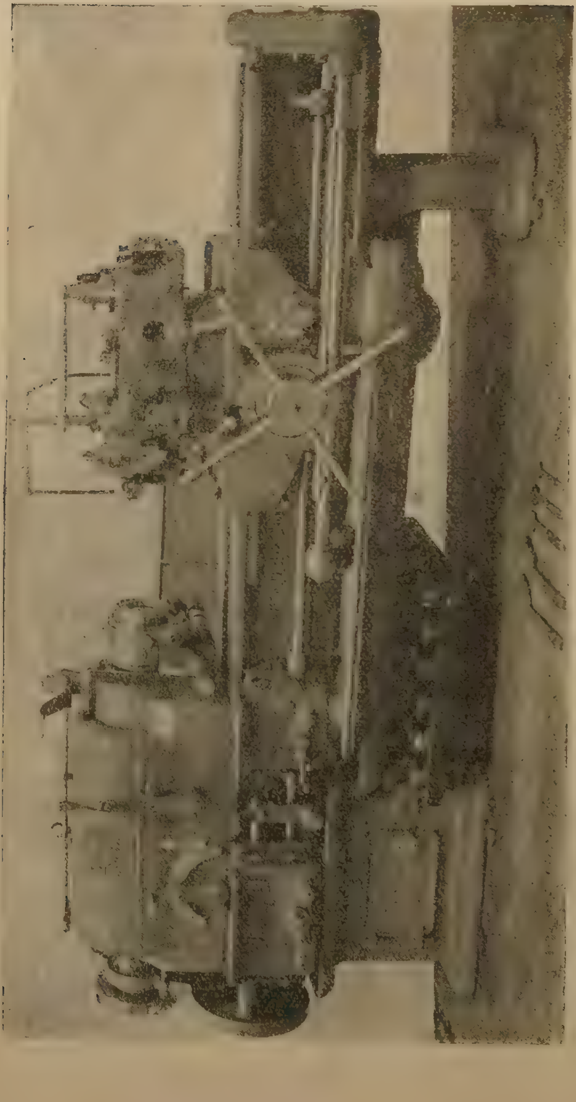


FIG. 211.—Hexagonal Turret Lathe, All-Geared Headstock, by Kendall & Gent, Ltd.

wheels on their shafts, and the final drive for slow speeds on the spindle is by means of a clutch of the ordinary claw type. The end of the spindle is screwed with a lever chuck of modern construction.

The chief feature of the headstock lies in the fact that all shafts, including the main spindle, are mounted on ball-bearings, a ball thrust bearing being of course added in the case of the main spindle to take up the thrust of the cutting tool. The high efficiency of the lathe, as shown by the tests, is attributed largely to this feature in its construction. The bed of the machine is of usual type, with square edges. The carriage is arranged to form a trough with a lip draining all the suds into the centre of the bed, and is provided with a hexagonal turret to the faces of which the turning tools, etc., are bolted.

The turning equipment includes a tool-holder block of forged steel, having a recess in which the tool can be clamped by means of two steel slotted clamps spanning the tools, and let into recesses in the body of the block. These are provided with set screws on the underside for securing the tool.

This block and tool, etc., travel on a slide formed on the main casting of the turning tool, which is of steel, and which is carried forward in order to form a housing for the circular arms carrying the rollers constituting the roller steady. The tool-holder block is moved to and fro on its slide by means of a worm fitted into the main body, operating in a rack with inclined teeth formed on the upper surface of the tool block. A stop and micrometer arrangement of the usual nature is fitted on the worm shaft in order to retain the size of the work after withdrawal of the tool.

The portion of the turning tool forming the roller steady is of special construction, and comprises that part of the main body casting referred to, which is carried forward beyond the tool slide, and which is shaped so as to form a circular recess in which can slide two similarly formed pieces, each provided with a hardened steel roller. The path of the circular recess is so situated as to be intersected by the bar or work at a point opposite or adjacent to the cutting point of the tool, so that the two rollers can be brought to bear against any work within the capacity of the machine.

The curved pieces carrying the rollers are detachably connected to two circular worm segments sliding in recesses concentric with and at the back of the recesses in which slide the roller carriers. These are operated by means of small worms retained in recesses in the main body and provided with means for micrometer adjustment and for locking. For the purpose of temporarily withdrawing a roller from the work, as, for instance, in left-hand turning, a roller carrier can be detached from the worm segment at the back by withdrawing a small pin, and can, of course, be returned to exactly the same position again and the pin reinserted. A chip deflector is also fitted to the lathe in order to direct the rapidly formed hot coils constituting the chip into the centre of the bed.

It will be noticed from the illustration that there are no projections on the roller steady in the direction of the head-stock, so that work can be turned, if desired, up to $\frac{1}{2}$ in. or so of the chuck. The cut-off and forming tools are also built up of steel castings, the slide carrying the tools being operated in the usual manner by means of a rack and pinion, a long hand lever being keyed on to the pinion shaft. A feature of this apparatus is the provision of a movable stop to the tool slide, thus enabling the parting-off tool to be set for the finished diameter of the work, for the purpose of finally squaring up the corner under the head of a bolt which is necessarily out of reach of the burnishing action of the rollers, and afterwards by withdrawing the stop to come to the centre for parting off.

The turret is rotated by hand and locked in the several positions by means of a hardened steel bolt, operated by a small handle in front of the carriage. The turret is connected by means of gearing with the stop bar shown in front of the lathe, so that as each face of the turret is presented to the work the corresponding stop comes into line with the lower end of a small plunger, carried in a bracket bolted to the apron of the carriage. The plunger is coned where it meets the stop so that further motion of the carriage raises the plunger, and this motion is utilised to throw the feed motion of the carriage out of gear. This can at any time be performed by hand by means of the small lever shown at the side of the plunger bracket. The feed is re-engaged by the upward motion of a vertical slide rod, provided with a handle, and conveniently placed on the apron.

The feeds are operated by means of a front shaft, gears, and rack, the latter being of steel, a turn-over handle seen at the end of the bed serving to reverse them. Three changes of speed are made by means of the vertical lever shown, which is clutched to a shaft fitted with a key sliding in a nest of three gears, a duplication of the feeds being effected by the second turn-over handle shown to the right. The lathe is provided with the usual tray, etc., for catching the suds with which the work must be flooded, and which is afterwards collected and returned to the cutting point by means of a pump, pipe, etc.

The following figures give the result of a series of tests taken on one of these lathes.

DETAILS OF A TEST OF A 10½-IN. CENTRE HEXAGON TURRET LATHE AT THE WORKS OF MESSRS KENDALL & GENT, MANCHESTER.

No. of Test.	Reducing a Bar		Feet per Minute on		Feed per Minute.	Cuts per Inch.	Material Removed				Horse Power (Electrically Measured).		
							Per Minute.		Per H.P. Min.				
	From	To	Original Diameter of Bar.	Mean Diameter of Bar.			Cubic Inches.	Lbs.	Cubic Inches.	Lbs.	Actual.	Loss on Motor.	Net taken by Machine.
	In.	In.			In.								
1	2¼	1	239	172	15	27	47·86	13·8	4·52	1·3	13·3	2·7	10·6
2	2	1	204	153	19½	20	45·95	13·2	4·50	1·3	12·7	2·5	10·2
3	2	¾	204	140	19½	20	52 65	15·2	5·16	1·5	12·7	2·5	10·2
4	1½	¾	233	175	29⅝	20	39·26	11·3	3·54	1·0	13·87	2·77	11·1

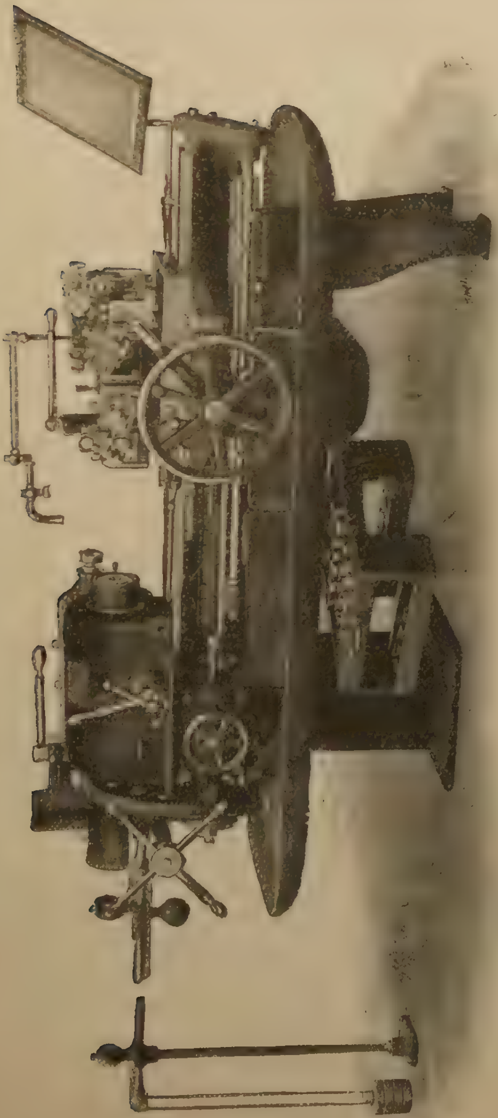


FIG. 212.—Hexagonal Turret Lathe.

Fig. 212 illustrates a modern type of hexagonal turret lathe by Alfred Herbert, Coventry. This machine produces finished work direct from the bar, and forging can also be machined.

The Drive.—The single pulley runs on ball-bearings at a constant speed, and requires no countershaft. The spindle bearings are lined with white metal. All spindle speeds are obtainable in either direction, and all the gears run in oil, and the bearings are either lubricated automatically or by continuous-feed lubricators. The speed variator is interlocked to prevent possibility of damage by incorrect manipulation. The operating levers are all made of steel, and are all conveniently placed. A speed plate on the head indicates how each speed is obtained.

The Bed.—The bed is a dry sand casting with large wearing surfaces, and of sufficient weight to absorb vibration. It is not subject to rapid downward wear as is the case with the narrow American vee beds.

The Turret Slide.—The turret slide is of unusual length. The projecting end passes under the chuck, enabling the turret to be brought close to the chuck.

Slide Motion.—The quick-power motion for moving the turret slide rapidly along the bed saves a great deal of labour and increases the output of the machine.

Pilot Wheel.—The pilot wheel on the apron is always free except when operated by hand, and so avoids all danger when the turret slide is being traversed by power.

The Turret.—The hexagon turret permits bars to pass clear through it. The tool holes are fitted with binding pads so that drills and reamers can be held, or bushes for supporting slender work while turning or forming. The tool holes are also relieved for rather more than half their circumference so as to prevent tools and bushes from jamming in the holes, and to enable them to be removed without damaging them. This also saves wear in the holes. The turret can be rotated in either direction, and in any position along the bed.

The Stops.—The automatic and dead stops act in either direction. Any number of the stops can be used for any tool, and any number of additional stops can be used. They are carried by a hexagon bar extending along the front of the bed, which is geared to rotate with the turret. The stops trip the feed, and act as dead stops. They are adjustable throughout the entire range of the lathe, do not project at the end of the bed, are in full sight at all times, and cannot get clogged up with chips.

Indicator.—The accurate indicator enables dead lengths to be obtained within the finest limits of error. Its effect is to ensure absolutely uniform pressure on the stops independent of changes in the pressure on the cutting tools as they become dull.

Feed Motion.—The feed changes are operated by a patent dial feed motion. The dial is marked to indicate the feeds in consecutive order. To obtain any feed, the dial is simply rotated until the number corresponding to the required feed comes into position.

The feeds are reversed by a handle on the feed box, and are suitable for a variety of work ranging from the fine feeds necessary for drilling small holes in hard steel, up to the coarse feeds used for reaming and machining cast metal. The feed gears are enclosed, and are lubricated automatically.

The Scale.—A graduated scale is fixed to the bed, and the turret slide carries an adjustable pointer.

The adjustment of the pointer enables it to be set to an even foot in any position of the turret slide.

By setting to zero when the tool is at the beginning of its cut, any length may be accurately turned without the use of a rule.

This appliance facilitates the production of the first of a series of pieces before the indicator or stops are set, and can also be used for the production of a small number of similar articles without using the stops.

Fig. 213 illustrates a capstan lathe of modern design. The single driving pulley runs on ball-bearings at a constant speed, and requires no countershaft. All the gears run in oil, and all bearings are automatically lubricated.

The Indicator.—The automatic bar feed furnished with the draw-in chuck is of simple design, and cannot get out of order. It is operated by an adjustable weight, and is exceedingly rapid in action. The tail-rod carries an adjustable ball-bearing revolving cat-head, which avoids the necessity for using feeding collars for every size of bar.

The Bed.—The bed is designed so as to be supported in the most efficient manner, and is strong and rigid. The oil tray is of large proportions.

The Capstan.—The capstan is of hexagon form, and the tool holes are relieved so as to enable tools and bushes to be inserted and removed easily, and to prevent wear of the holes. It has a clamping handle. The automatic movement can be disengaged when required, enabling the capstan to be rotated by hand in either direction. This is a convenience when using tools too large to swing over the capstan slide.

The Indicator.—A device for securing absolutely accurate dead length dimensions is fitted to the lathe.

Automatic Feed.—The feed box, which is totally enclosed, provides four feeds to the capstan slide. The gears in the feed box are all of steel, and run in an oil bath. An arrangement is provided for coupling the capstan slide to the saddle for boring and turning, using the automatic feed.

Capstan Stops.—The capstan slide carries a hexagon

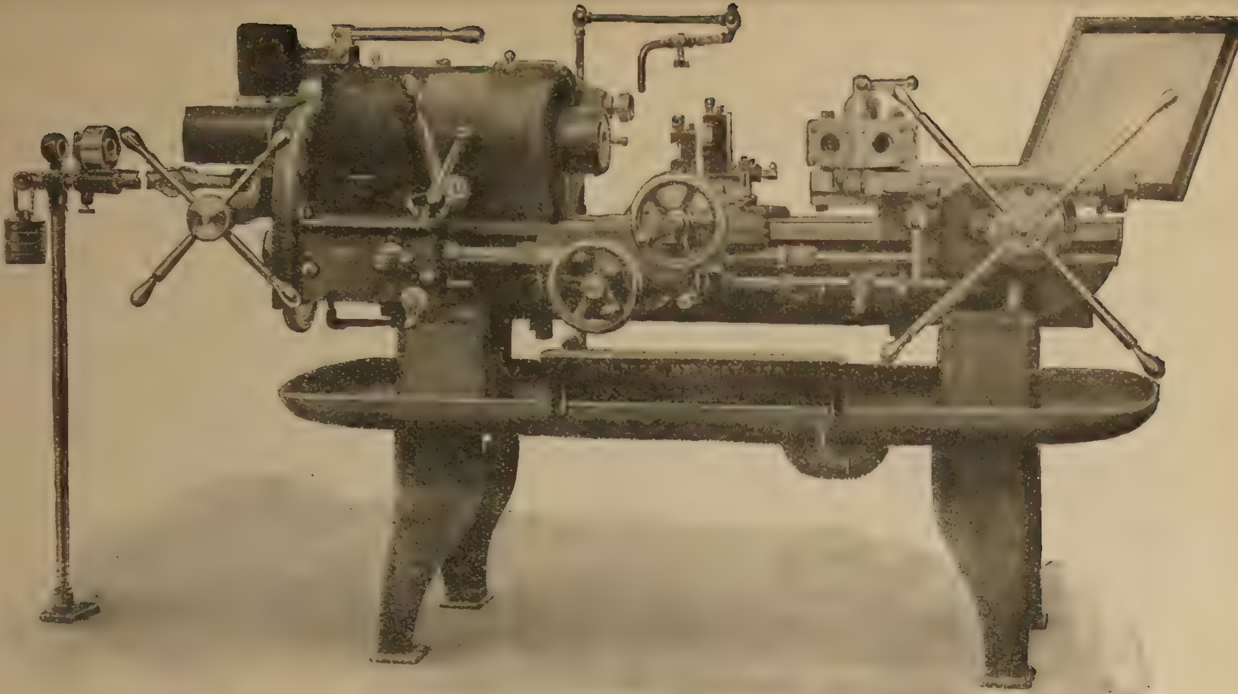


FIG. 213.—Capstan Lathe, all Gears, with Single Pulley Drive.

stop bar geared to rotate with the capstan, and is provided with six adjustable stops. The stops trip the feed, and act as dead stops, and are all provided with fine adjustment screws.

Chasing.—The chasing saddle is operated along the bed by rack and pinion, and has eight adjustable stops, four transversely and four longitudinally. By the use of these stops two dimensions in either direction can be produced with the same tools. The transverse stops are protected by an easily removable guard. The hand wheel for operating the cross movement has an adjustable index disc. By using this disc as a measure of the pressure on the dead stops very accurate diameters can be turned.

The Chasing Gear.—The chasing gear consists of a leader which can be changed to suit different pitches. This leader is driven by gearing in the feed box, and will cut pitches which are sub-multiples of its own pitch in the ratio of 1, 2, 3, and 4. For instance, a 4 per inch leader will cut 4, 8, 12, or 16 threads per inch. Provision is made for cutting right and left hand screws, the leader being reversed by a lever on the feed box.

The nut is connected with the tool slide in such a way that when it is withdrawn from the leader the tool or chaser is simultaneously withdrawn from its cut, and *vice versa*, the additional depth of cut for each successive travel over the work being obtained by the cross-feed screw.

Tapers.—A taper attachment by means of which either internal or external taper chasing or turning can be done.

Tool Posts.—The tool posts are of the swivelling open-side type, and permit straight tools to be used close up to the chuck face. Screw elevating wedges regulate the height of the tools without packing.

Turret.—A square turret for the cross slide can be fitted if required, and is of great use for lathes intended for chuck work.

Examples of Capstan Lathe Work

Fig. 214 shows several examples of the kind of work done on this type of capstan lathe.

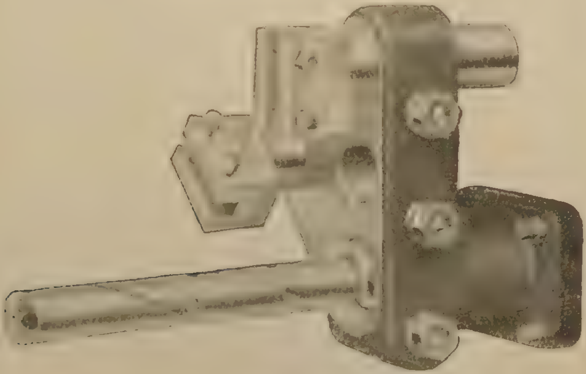


FIG. 215.—Combination Boring, Turning, and Facing Tool Holder.

Fig. 215 illustrates a combination turning, boring, and facing tool holder. This tool is used in the capstan head for such purposes as finishing castings and forgings of

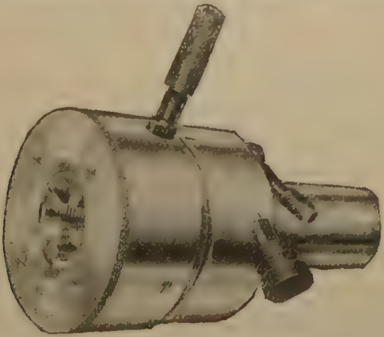


FIG. 216.—"Coventry" Self-Opening Die Head.

irregular shape, such as spur and bevel gear blanks, cylinder covers, etc. They are universal, and will deal with work of almost any imaginable shape.

For screwing work in the capstan lathe the "Coventry" self-opening die head will be found to be a very satisfactory and accurate tool. Fig. 216 illustrates this tool. The dies can be changed and adjusted, and the die head entirely operated without the use of a spanner or other tool. The dies are caused to be opened at the proper point by arresting the capstan slide by means of an adjustable stop fitted to the capstan head, or by other suitable means.

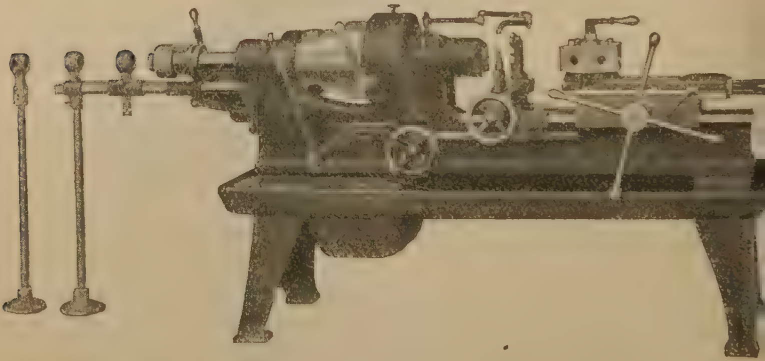


Fig. 217.—Geared Friction Head Turret Machine.

Turret Head Machine

Fig. 217 illustrates a useful type of geared friction head turret machine. The head and bed are cast in one piece, ensuring strength and rigidity. The cone has three steps. The back gears are engaged and disengaged by friction clutches, and all gears are completely protected by metal guards. The geared friction head gives two spindle speeds for each speed of the cone. The automatic chuck and wire feed is operated by a patented link motion, or by a turnstile, rack, and pinion. The sliding wedge is stepped so as to adjust the collet automatically for slightly varying diameters. The illustration does not show the wire feed rod and supports.

The turret is revolved automatically by the backward movement of the slide. The six tool holes are provided with binder bushings for securing the tools. The locking bolt is at the front end of the slide, directly under the cutting tool, and works into steel taper bushings pressed into the bottom of the turret at nearly its full diameter. Independent and adjustable stops are provided for each tool.

The turret saddle has a supplementary taper base giving vertical adjustment to the turret; and taper gibs on each side provide for horizontal adjustment, so that correct alignment with the spindle can always be maintained.

A cut-off slide carries two tool posts of different heights, and is operated by a hand wheel and screw. A hand longitudinal feed can be fitted to special order when desired.

A geared pump operates when running in either direction, and delivers a copious stream of oil to the cutting tools.

Automatic feed to the turret slide can be fitted if required. It is gear driven, with four changes, any of which can be instantly obtained.

Specially large chucks are furnished by the makers when required for holding short pieces of greater diameter than the spindle will pass.

Another extremely useful type of capstan lathe is shown at Fig. 218. In this machine the headstock is powerfully built, and has pulleys of large size with two or three steps. The spindle is of forged steel, ground and hardened, the thrust being taken by ball-bearings. The bearings are either of phosphor bronze or split babbit metal with ring lubrication. Stops are provided to regulate depth of cut in either direction.

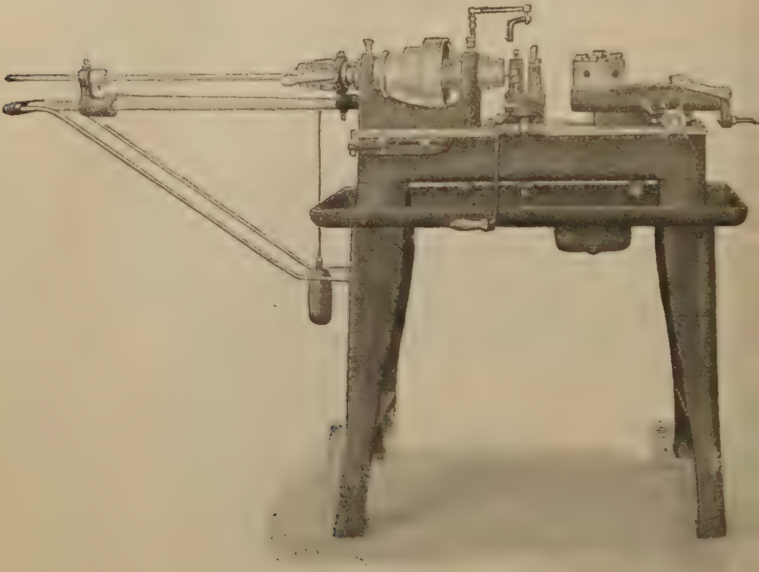


FIG. 218.—Capstan Lathe.

The turret is round, and is provided with six holes. After completion of the work by any tool, the turret slide is brought back, and up again to the work, and this automatically turns the turret into its new position. Six stops are provided for the turret, each of which, corresponding with the tool in use, comes automatically into position.

CHAPTER XVI

CAPSTAN AND TURRET LATHE TOOLS

THE successful use of capstan and turret lathe tools, depends to a very great extent, upon the cutting and clearance angles of the tools being carefully and accurately ground, to the most suitable angle for the metal and work being turned.

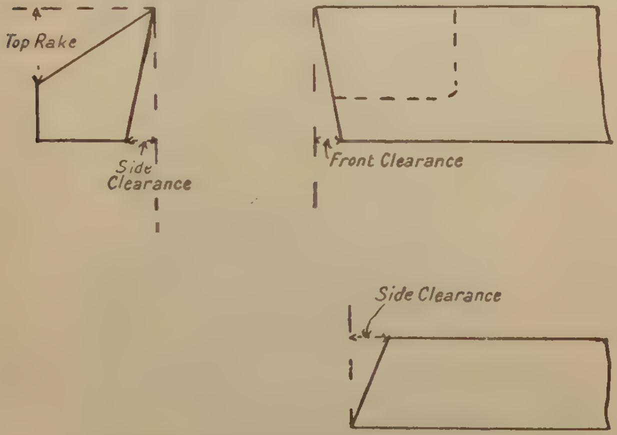


FIG. 219.—Capstan and Turret Lathe Tools.

It is necessary that the tool should have its top and side rake as great as possible consistent with strength and allowance for wear. The clearances in all cases should be as little as possible. Figs. 219 and 220 show tools used

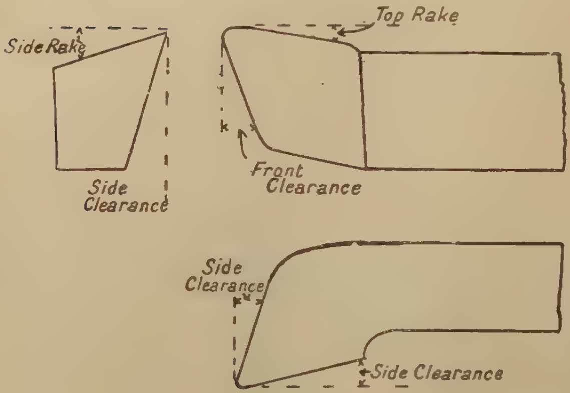


FIG. 220.—Capstan and Turret Lathe Tools.

in capstan and turret lathes for bar work, and the following figures give the rake and clearance most suitable for turning various metals :—

<table>
<tr><th colspan="5">TURNING AND FACING TOOLS.</th></tr>
<tr><th>Metal.</th><th>Top Rake.</th><th>Side Rake.</th><th>Front Clearance.</th><th>Side Clearance.</th></tr>
<tr><td>Steel - -</td><td>12°</td><td>12°</td><td>12°</td><td>12°</td></tr>
<tr><td>Cast Iron -</td><td>8°</td><td>8°</td><td>12°</td><td>12°</td></tr>
<tr><td>Brass - -</td><td>0°</td><td>0°</td><td>12°</td><td>12°</td></tr>
<tr><th colspan="5">PARTING TOOLS.</th></tr>
<tr><td>Steel - -</td><td>12°</td><td>0°</td><td>12°</td><td>2°</td></tr>
<tr><td>Cast Iron -</td><td>1°</td><td>0°</td><td>12°</td><td>2°</td></tr>
<tr><td>Brass - -</td><td>0°</td><td>0°</td><td>12°</td><td>2°</td></tr>
<tr><th colspan="5">KNIFE TOOLS.</th></tr>
<tr><td>Steel - -</td><td>0°</td><td>35°</td><td>8°</td><td>7°</td></tr>
</table>

Chucking Tools

An important point in the use of capstan or turret lathe in chucking operations is that the cutting edge of the

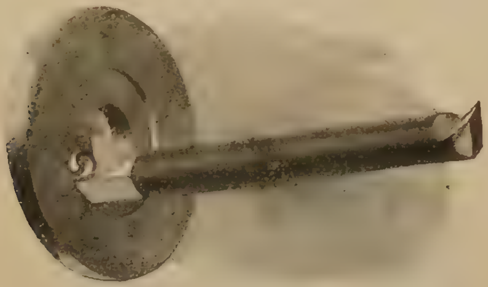


FIG. 221.—Facing Tool.

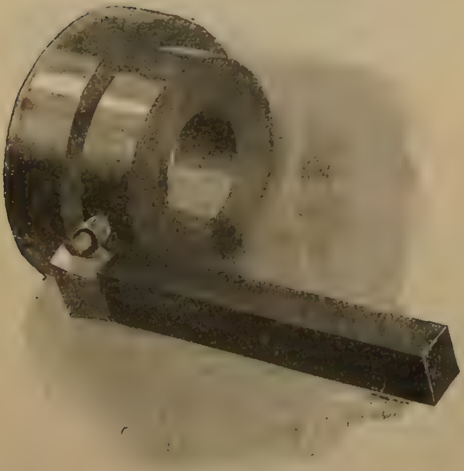


FIG. 222.—Turning Tool.

tool must never project beyond the holder more than is absolutely necessary. After the tool has been ground to the required angle, it is necessary to see that the feed is sufficiently coarse to prevent the cutting edge of the tool scraping and losing its keenness. A heavy built lathe is more suitable for chucking work than a light machine, but even with a very stiffly built machine work is frequently spoilt owing to the use of too fine a feed. Chattering, which is due to want of rigidity and vibration, can often be remedied by simply increasing the feed of the machine.

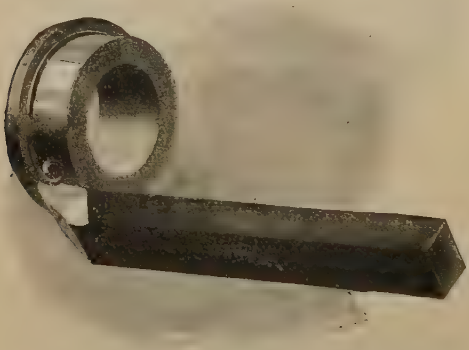


FIG. 223.—Cornering Tool.

Fig. 221 illustrates a facing tool as used for chucking work in the Hartness flat turret lathe. The advantage of using a round section tool for facing lies in the fact that it can be turned to give any desired rake.

A square section turning tool is shown in Fig. 222, a cornering tool in Fig. 223, and a back facing tool in Fig. 224.

Roller Turner

The roller turner illustrated in Fig 225 is provided with a roller back rest. It has two independent adjustments for turning two sizes, and it may be quickly opened to pass over a large diameter and instantly closed to either of the two sizes for which it has been set.

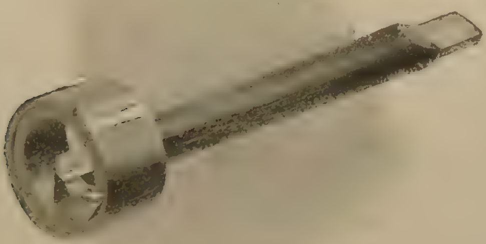


FIG. 224.—Back Facing Tool.

The rolls may be arranged to precede or follow the cutter, and they are run on straight headless pins hardened and ground These pins are held by a rocket inducing an axis in parallelism with the work.

Universal Turner

A universal turner with roller back rests is shown in Fig. 226. This type of turner is used by the Pratt and Whitney Company, and is suitable for bar work. It is found equally effective for turning towards the spindle, as is usually the practice on short work, or away from

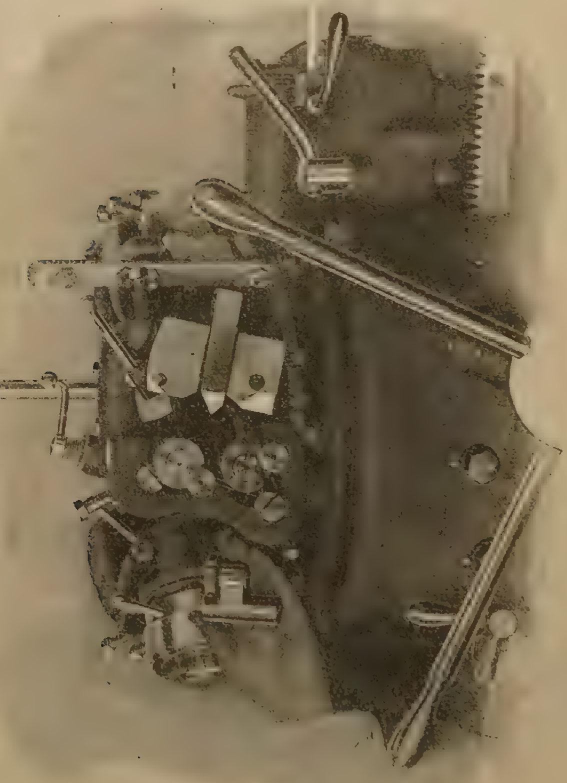


FIG. 225.—Turret arrangement, showing Roller Turner.

the spindle, which is often desirable on long slender work.

The cutter is mounted in a slide provided with a radial adjustment, which is governed by stops. The back rest rolls are made of high-speed steel hardened and ground, and run on hardened tool steel studs. The jaws are reversible for either leading or following the work.

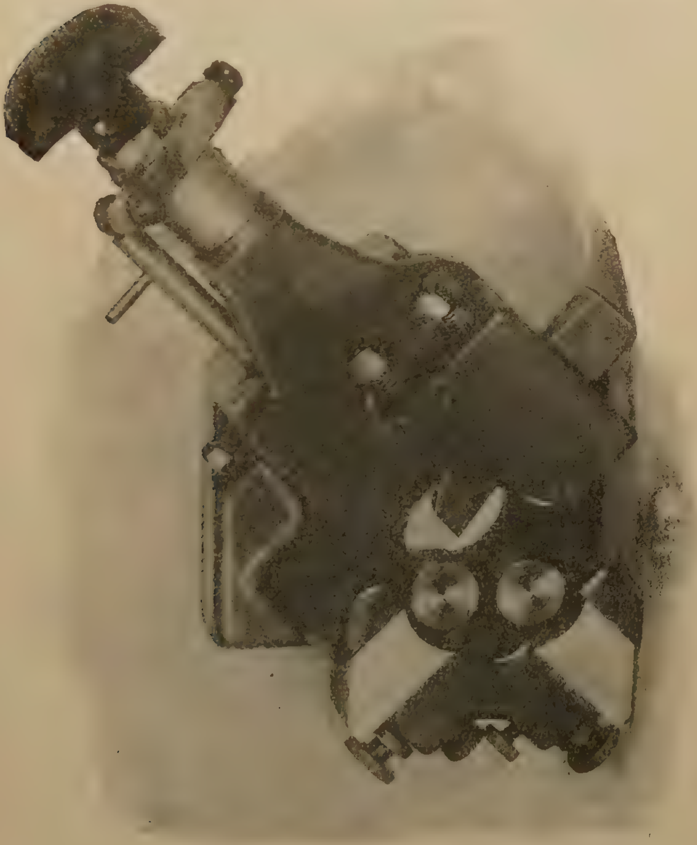


FIG. 226.—Universal Turner, with Roller Back Rests.

Single Turner

A single turner with tangent cutter is illustrated in Fig. 227. This type of cutter is very rigid, but at the same me is sensitive and easily adjusted. The cutter is located overshot tangent to the work, and the back rests are wedge-shaped.

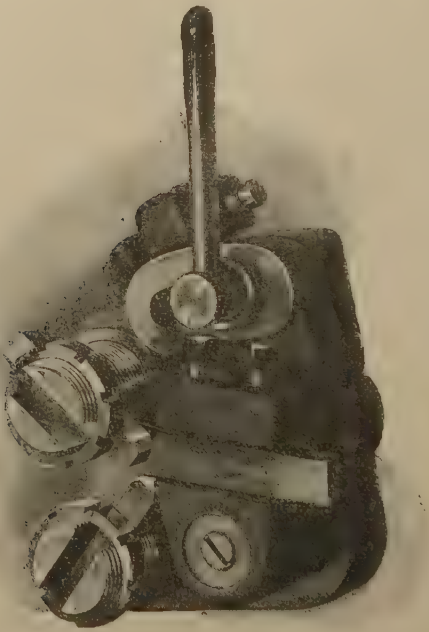


FIG. 227.—Single Turner Tangent Cutter.

Another type of single turner is shown in Fig. 228. This is similar to the previous examples, with the exception that very back rests are fitted.

Open Side Turner

The turner shown in Fig. 229 is occasionally used for special work having a short cut. This type of turner is only recommended for taking light cuts.

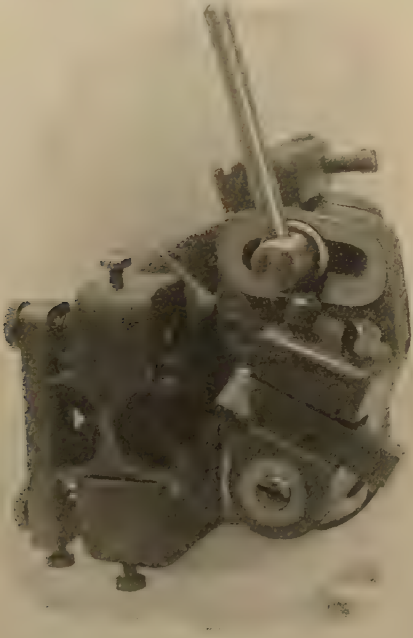


FIG. 228.—Single Turner, with Tangent Cutter.

Taper Turning Tool

A taper turning tool suitable for turning tapers from either bar stock or forgings is shown in Fig. 230. The cutting tool is directly controlled by an accurate taper bar

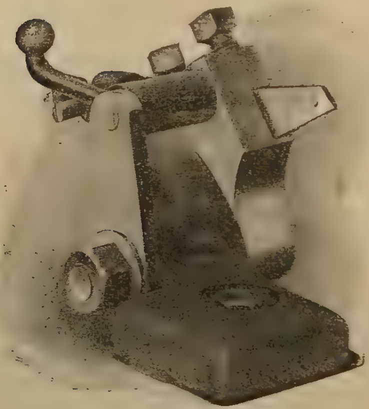


FIG. 229.—Open Side Turner.

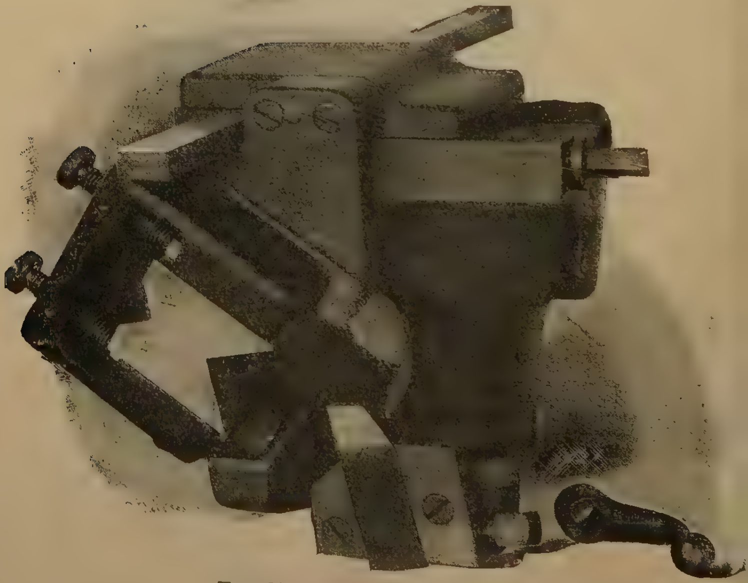


FIG. 230. —Taper Turning Tool.

for the angle, and the work produced is equal to that obtained from an engine lathe.

The radial adjustment of the tool slide, which permits roughing or finishing cuts, is accomplished through the taper bar-block screw, accurate adjustments being possible by means of a micrometer dial. In order to produce the required taper it is only necessary to plane a bar to a taper one-half of that required on the piece of work to be turned; thus, if the required taper is ½ in. to the foot, the bar should be planed ¼ in. to the foot.

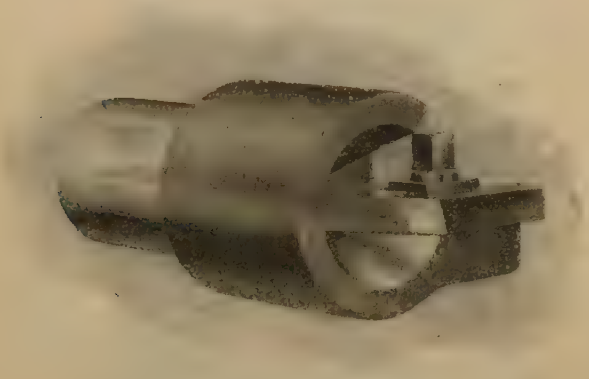


Fig. 231.—Bell-Mouth Pointing Tool.

Bell-Mouth Pointing Tool

The tool shown in Fig. 231 is used for chamfering the ends of rough work preparatory to turning.

End Forming and Pointing Tool

The end forming and pointing tool shown in Fig. 232 is used for general end forming and pointing work on finished bars, and for this purpose it is provided with adjustable back rests. Both the jaws and the cutters are made of high-speed steel.

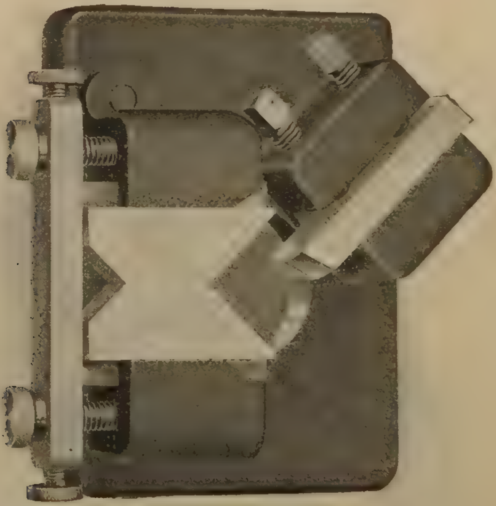


Fig. 232.—End Forming Tool.

Centring Tool

Fig. 233 illustrates a centring tool for drilling centres in work. By careful adjustment of two of the back rests, just a little nearer the centre than the third rest, absolutely true centring can be done.

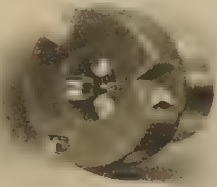


FIG. 233.—Centring Tool.

Clutch Tap Holder

The clutch tap holder shown in Fig. 234 is used for holding a tap against turning until it has tapped to a desired depth, at which point the carriage is stopped, causing the clutches to pull apart and allowing the tap to rotate with the work until the spindle is reversed for screwing it out.

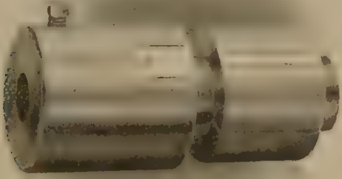


FIG. 234.—Clutch Tap Holder.

Tool Holders

Fig. 235 illustrates a type of tool holder used for holding round shank tools or die-heads.

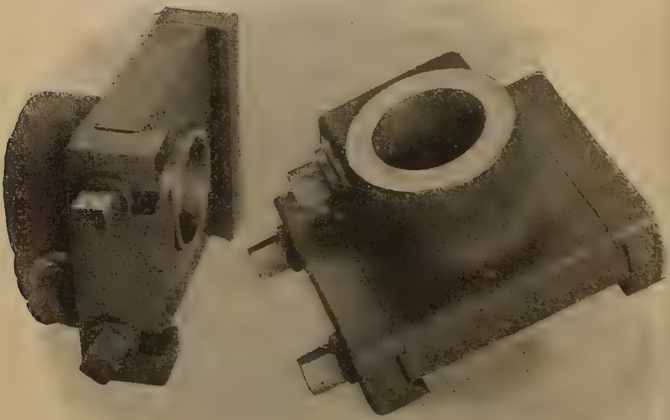


FIG. 235.—Round Tool Holders.

Step Chuck and Closer

A Pratt and Whitney step chuck and closer is shown in Fig. 236. The various parts are clearly shown in the illustration.

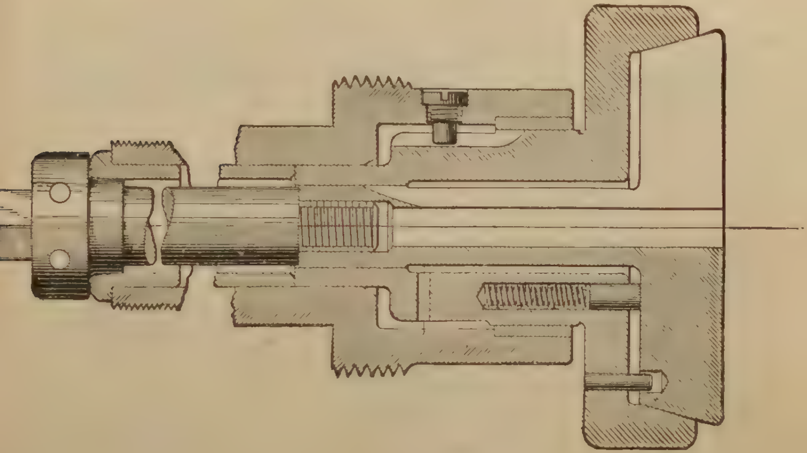


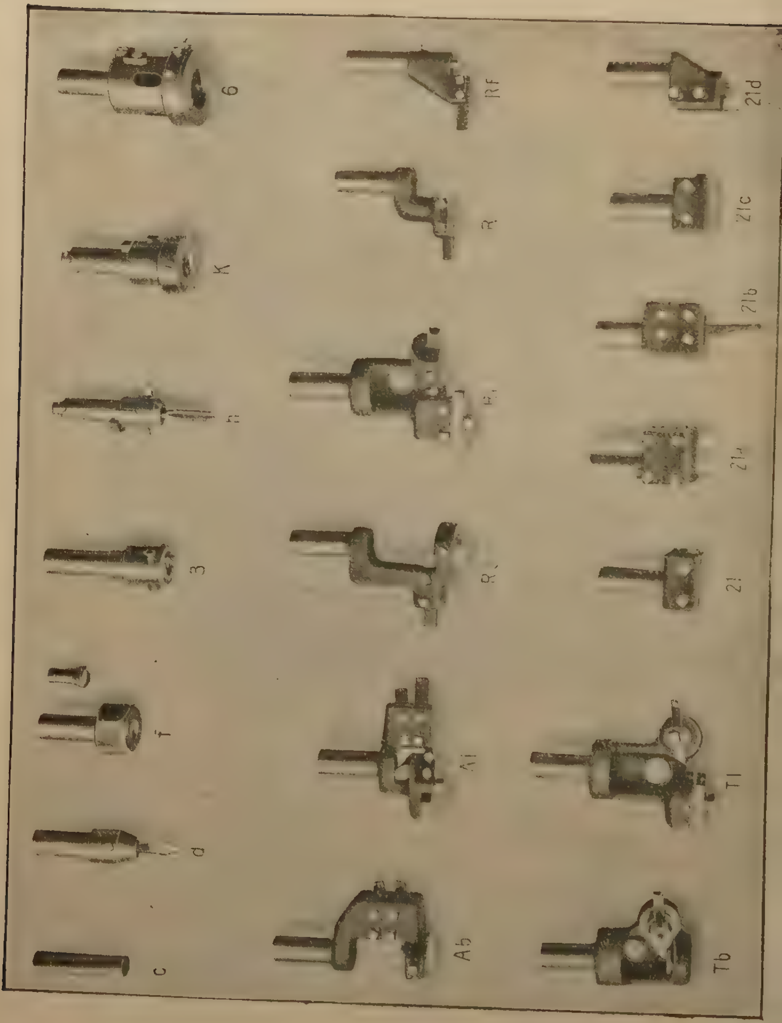
FIG. 236.—Step Chuck and Closer.

Capstan Lathe Tools

A full set of capstan lathe tools, as used with the capstan lathe (Fig. 218), are shown in Fig. 237.

The various tools are named as follows :—

c. Positive stop.
d. Centring tool.
f. Special tool holders.
3. Drill chuck.
h. Automatic tap chuck.
K. Automatic chasing die-holder.
6. Releasing die head.
A *b.* Roughing tool.
A *e.* Roughing tool with end stop.
R *b.* Finishing tool with radial cutter.
R *e.* Finishing tool with stay guide.
R. Finishing tool with bush guide.
R *f.* Finishing tool.
T *b.* Finishing tool with tangential cutter.
T *e.* Finishing tool with stay guide.
21. Tool box open at front.
21 *a.* Special tool box.
21 *b.* Tool box, special tool.
21 *c.* Tool box closed.
21 *d.* Tool box open.


6
K
h
3
f
d
c
RF
R
H1
R1
A1
Ab
21d
21c
21b
21a
21
T1
Tb

CHAPTER XVII

BORING AND SLOTTING MACHINES

Boring machines, as with all other types of modern machine tools, are constructed in a great variety of forms and sizes. They can roughly be divided into horizontal machines, where the work is stationary and the tool moves, and vertical machines, in which the work rotates. In appearance, the horizontal machine resembles the modern lathe, the boring head carrying the boring bar or boring tool, the work being secured to the table of the machine. The great advantage the boring machine has over the lathe lies in the fact that several operations can be performed at the same time and with one setting of the job.

A modern type of horizontal machine is illustrated at Fig. 238. This particular class of machine is called a surfacing, boring, milling, and drilling machine; it has a single pulley drive which is readily adaptable for driving by belt direct from an electric motor, or from a countershaft. Twenty-four different speeds can be obtained by means of the headstock gearing and speed box. The speed box is provided with sliding gears and friction clutches, operated by levers in front of the machine, and only gears actually in use are in mesh.

The sliding head is of rigid construction, and is provided with automatic feeds and rapid power traverse in either upward or downward direction. The chuck can be removed so that large milling cutters may be carried on the spindle. For surfacing, a facing slide is provided for fitting to the chuck, with automatic feeds either from or to the centre. A taper plug accurately locates the slide in the central position, and an arrangement is provided by which the nut at the back of the facing slide can be adjusted in

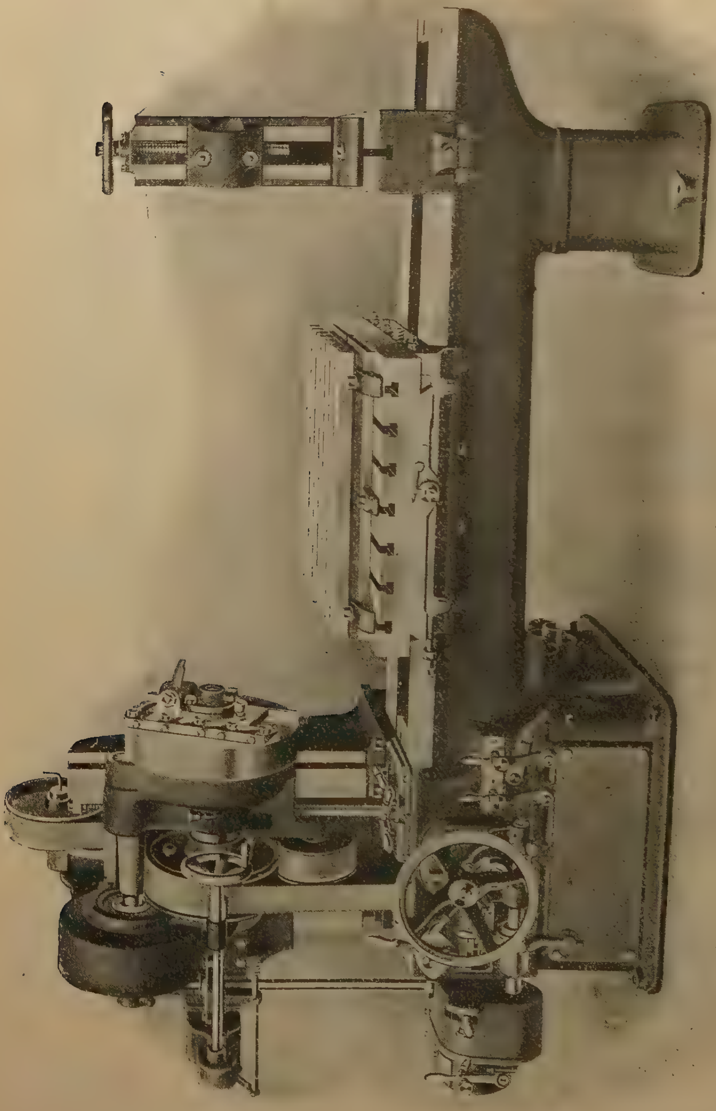


FIG. 238.—High-Speed Boring Machine, by Alfred Herbert, Ltd.

either of two positions, enabling full advantage to be taken of the extreme range of travel.

The bed of the machine is of box section, providing a rigid foundation for the other parts of the machine. The feed mechanism gives eight longitudinal and transverse feeds, and a feed safety device is provided for all feeds, which prevents damage through the operator allowing them to overrun. The main table has automatic longitudinal and cross feed and rapid power traverse to both motions in either direction. A spacing arrangement can be fitted to the side of the table, enabling holes to be accurately bored any specified distance apart by means of a gauge instead of by measurement.

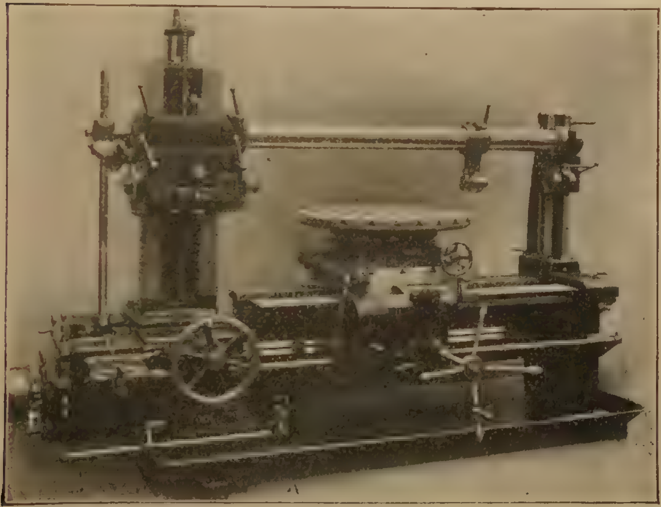


FIG. 239.—Horizontal Boring Machine.

The detachable table can be rotated on a pivot, and has locating notches for the exact right angle positions.

Fig. 239 illustrates a type of boring machine specially designed for the rapid production of engine and machine tool parts, particularly in connection with jig work. This machine has several features which render it useful in rapidly handling work where combined boring, drilling, and milling operations are necessary.

The driving and feed gears are carried at the end of the bed in boxes with lids for inspection, and run in an oil bath. The speed changes are made by handles so interlocked as to prevent wrong gears being engaged. The spindle runs on ball journal bearings, and has ball thrust in either direction. The elevating screw for the vertical adjustment of the head has a ball thrust, and is graduated to read to .001 inch. In addition to the hand adjustment, a vertical milling feed is provided with four changes of speed.

The table has four tee slots with cross grooves to facilitate the setting of jigs and similar pieces of work. Automatic cross traverse is provided in either direction, and is at a suitable rate for milling. Longitudinal traverse in either direction can be obtained automatically with four changes of feed.

The outboard bearing gives support to the boring bars, and is arranged to maintain perfect alignment with the spindle.

It is impossible for the longitudinal and cross feeds to be in operation at the same time. The interlocking is governed by a small crank handle at the bottom of the apron, with an index plate which corresponds with the position of the handle, clearly showing the motion engaged. A half turn of the handle changes from one to the other.

Combined Surfacing, Boring, Milling, Drilling, and Tapping Machine

The importance of performing such varied operations as boring, milling, drilling, and tapping at one setting of the work will be readily appreciated when the increasing ratio of time spent in setting up a job is taken into consideration. By using a machine of this character the time taken in setting up a job is reduced to a minimum, so that not only are the labour charges reduced, but the productive capacity of the machine, due to lessened time in setting, is greatly increased.

The general design of the machine is shown in Fig. 240. The bed of the machine is of box section with internal ribs, and is carried down to the floor. No special foundation is necessary. The control levers for all parts are on the front of the bed, so that the operator can conveniently manipulate them to obtain any required adjustment by hand or power without losing sight of the work.

The change speed box is disposed outside the bed, and is so arranged that it is readily accessible for examination or removal without disturbing any other parts. With this speed box it is possible to obtain thirty-two variations of speed, in geometrical progression. The sliding gears in the gear box provide four speeds, and are controlled by two "speed variator" levers. By moving the starting lever to the right or left, two other speed changes are effected, and thus the gearing on the machine bed gives eight speeds. The drive from the pulley at the base of the machine to the spindle is effected by a belt and by the gearing on the main spindle. This gearing gives four speed changes, two speeds being transmitted by means of a pinion direct on to the facing head, and the other two by means of separate gears.

For large diameter work, the drive is direct to the facing head, so removing all torsional stress from the spindle.

The following table shows the high gear purchase provided, which gives ample power at the tool, and consequently smooth running under heavy cuts.

DIAMETER OF SPINDLE PULLEY, 19 IN.; BELT, $4\frac{1}{2}$ IN. WIDE.

Revolutions per Minute		162	138	121	104	94	81	71	61	58	51	45	38	34	30	26	22
Diameter of Work	At 20 feet	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{7}{8}$	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2	$2\frac{1}{4}$	$2\frac{1}{2}$	3	$3\frac{1}{2}$
	,, 30 ,,	$1\frac{1}{16}$	$\frac{7}{8}$	$\frac{15}{16}$	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{5}{8}$	$1\frac{7}{8}$	2	$2\frac{1}{4}$	$2\frac{5}{8}$	3	$3\frac{3}{8}$	$3\frac{3}{4}$	$4\frac{1}{2}$	5
	,, 40 ,,	$\frac{15}{16}$	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{7}{8}$	$2\frac{1}{4}$	$2\frac{1}{2}$	$2\frac{3}{4}$	3	$3\frac{1}{2}$	4	$4\frac{1}{2}$	5	6	7
Gearing Ratio.		Spindle Speed.								2·72 to 1 gear.							

Revolutions per Minute		19	16	14	12	10 9	9·4	8·2	7	6·4	5·8	5·1	4·4	3·97	3·42	3	2·6
Diameter of Work	At 20 feet	4	$4\frac{3}{4}$	$5\frac{1}{2}$	$6\frac{1}{4}$	7	8	$9\frac{1}{2}$	$10\frac{1}{2}$	12	13	15	17	19	22	25	30
	,, 30 ,,	6	7	$8\frac{1}{4}$	$9\frac{1}{2}$	$10\frac{1}{2}$	12	14	16	18	20	22	26	30	34	39	44
	,, 40 ,,	8	$9\frac{1}{2}$	11	13	14	16	19	21	24	26	30	34	38	44	50	60
Gearing Ratio.		8·65 to 1 gear.								23·57 to 1 gear.							

The machine is fitted with a variable feed gear giving eight rates of positive feed, varying between 100 to 8 cuts per inch, all instantly changeable and reversible. They can be applied to the longitudinal, transverse, and vertical slide movements.

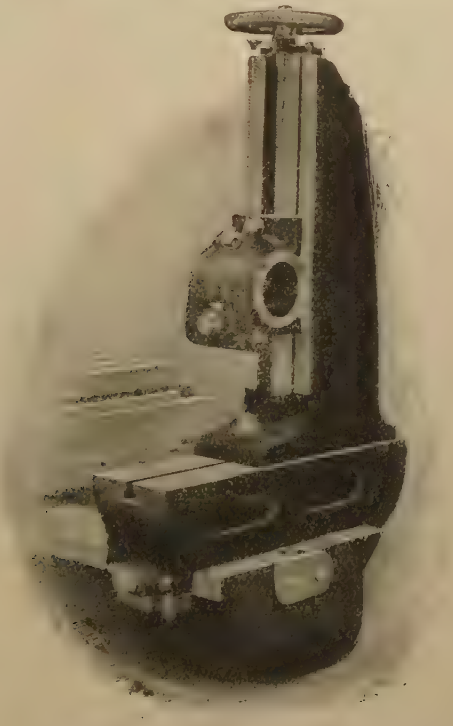


Fig. 241.—Boring Stay, with Hinged Cap.

The screw-cutting gear comprises a swing frame, specially fitted to the machine, and change wheels suitable for threads from 2 to 16 per inch.

Four different methods of driving may be adopted as follows :—

(1) By single pulley and change speed gear box.
(2) By constant speed motor and change speed gear box.
(3) By variable speed motor
(4) By two-speed countershaft having four-step cone.

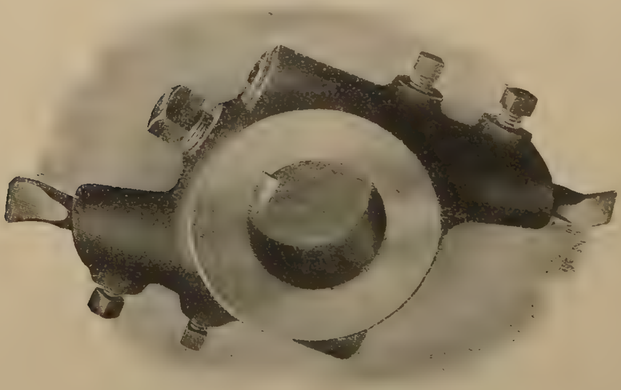


Fig. 242.—Steel Boring Head.

Tapping.—When the machine is required for tapping, the drive must be reversible, a countershaft with open or crossed belts or a reversible motor being employed.

Gear for Slide.—The tool is secured in the tool-holder or slide by a square-headed screw of large diameter, the tool-holder being traversed across the facing head by two pinions.

The Boring Stay is of rigid construction, as shown in Fig. 241; it is capable of carrying boring bars of large diameter, and is mounted upon a saddle, which can be secured in any position along the bed. The bearing for supporting the bar has a hinged cap, the joint of which is placed at an angle; by this construction the bar does not require its full length for insertion; further, it is supported by the stay, whilst the cap is being secured.

Boring Head.—Fig. 242 illustrates one type of cast-steel boring head used in conjunction with the boring bar.

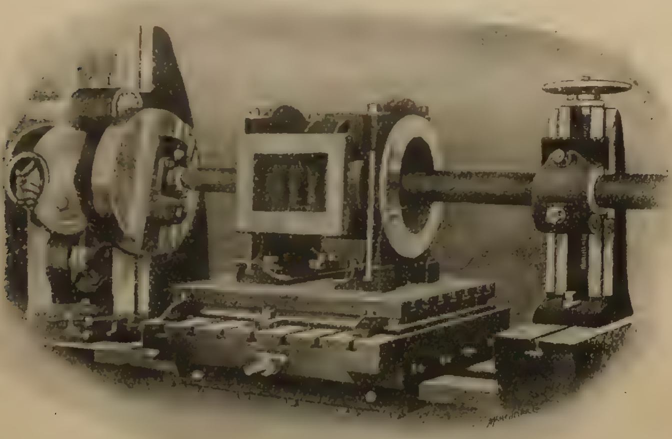


FIG. 243.—Cylinder being Machined.

Fig. 243 shows the setting up of a steam engine cylinder ready for machining the bore, the flanges, and the valve chest, the various operations being carried out without the removal of the casting from the turntable.

Fig. 244 illustrates the machining of a connecting rod. By the use of sliding bars and the vee block upon which the rod is clamped, and which are tongued into the table, the crosshead end may be brought truly into position, thus ensuring the alignment and parallelism of the two holes.

Fig. 245 shows the machine arranged for facing the flange, and boring the recess for crankshaft bearings by a tool in the facing head slide, one part of the job being held in vee block.

A useful type of horizontal boring machine supplied by Messrs Selson Engineering Co., London, is shown at Fig. 246.

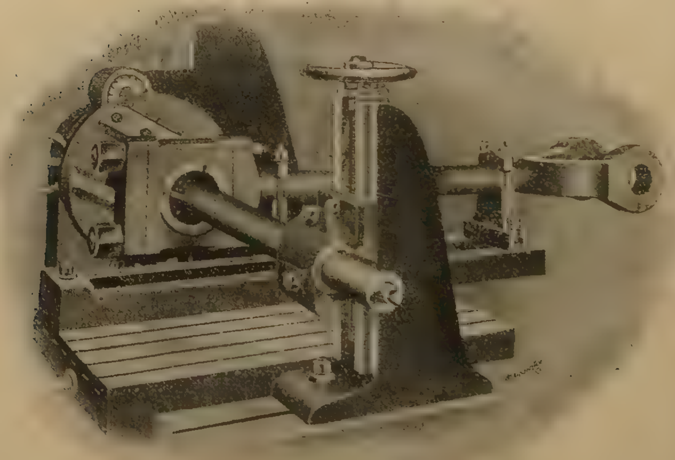


Fig. 244.—Connecting Rod Set for Machining.

In the design of this machine will be found several features of interest, such as the deep bed of great rigidity, which makes the machine self-contained and a foundation unnecessary, and ensures perfect alignment of the table with the spindle and outer support at all times. All the gears are of steel, of heavy pitch; all the bearings are large and bronze bushed, and all moving parts are covered.

The Spindle Head and outer support for boring bar are raised and lowered simultaneously by power or hand. It is fitted with an automatic safety trip to prevent any accident due to carelessness.

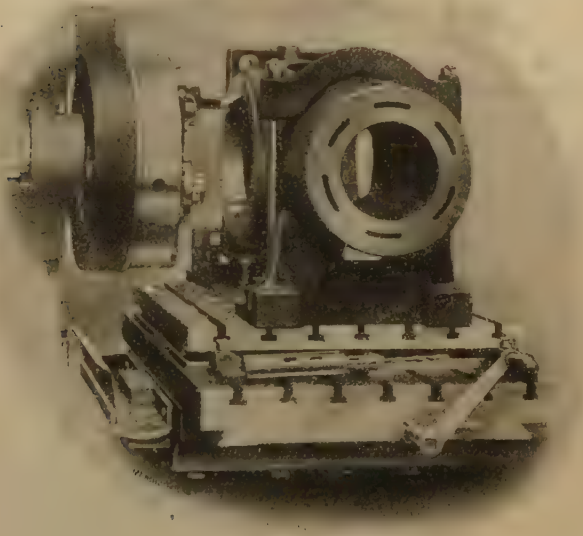


FIG. 245.—Facing and Boring Recess for Crankshaft Bearings.

The Spindle is of crucible steel, 3 in. in diameter, accurately ground, and is fitted with a Morse taper. It passes through a cast-iron sleeve, and is driven by a large key. The thrust is taken up on ball-bearings.

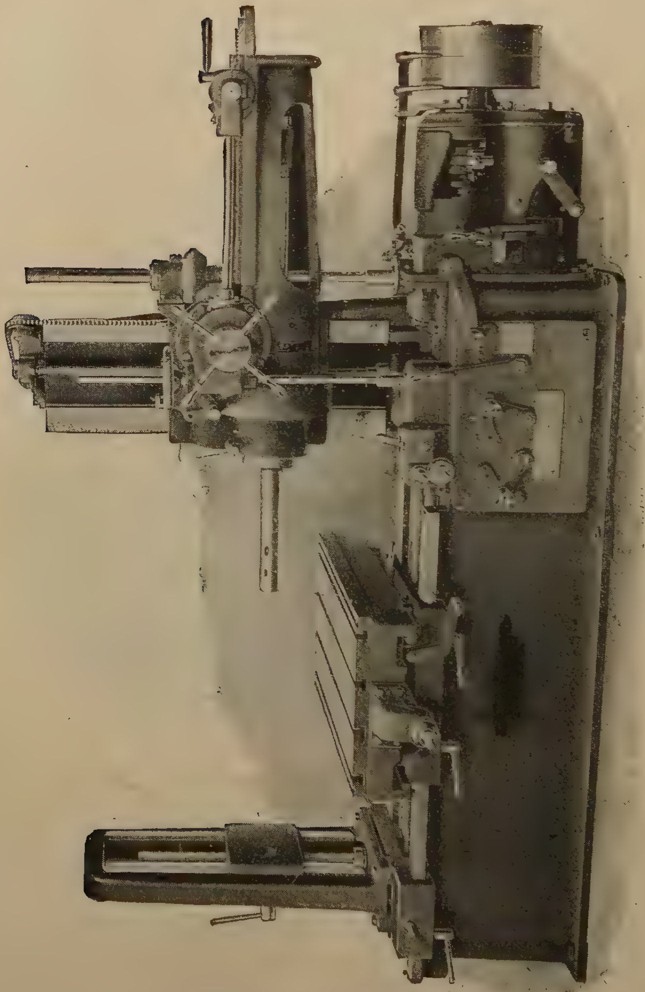


FIG. 246.—Horizontal Boring Machine.

The Sleeve runs in bronze bearings and carries the driving gear. It is equipped with a device whereby the spindle can be held in line after any amount of wear. The front of the sleeve forms a face plate to which large milling cutters, facing heads, or other tools may be attached, thereby relieving the spindle bar of a lot of work; and also eliminating chattering when using large milling cutters.

The Table is of heavy construction, has T slots planed in it, and is scraped absolutely square with a line passing through the centre of the spindle. An automatic safety stop is provided to prevent breakages due to carelessness of the operator. It has a longitudinal motion by hand, and a cross motion by hand or power.

There are eight changes of feed, all reversible, and all obtained through one box.

The Adjustments of the spindle head, platen, and outer support are made of screws, accurately chased. The ends are provided with micrometer collars, graduated to .001 part of an inch, making it possible to bore, drill, and mill surfaces to exact distances apart, without the use of jigs, which makes it an invaluable machine for the tool room or wherever great accuracy is required.

The Drive is either through the cone or speed box. A four-step cone pulley is used, the largest step of which is $14 \times 3\frac{3}{4}$ in., permitting the use of a 3-in. belt. The speed box is provided with eight changes of speed, all instantly available. Both cone and speed box drives can be started and stopped from the front of the machine by a conveniently located lever. The machine can be reversed by the use of a reversible countershaft.

Fig. 247 illustrates a rotary table used in conjunction with this machine. By use of this table work can be drilled, bored, and milled in any direction without resetting the casting. The base of the attachment is tongued and securely bolted to the platen of the machine by four bolts. The throat on the T slots in the top of the platen are planed so as to allow jigs and other fixtures to be tongued to it. The outside periphery of the platen is graduated to one-half of a degree. The worm and hand wheel shown can be easily withdrawn, leaving the table free.

The attachment shown at Fig. 248 is made so that it can either be bolted directly on the spindle sleeve, or clamped in any desired position on the boring bar.

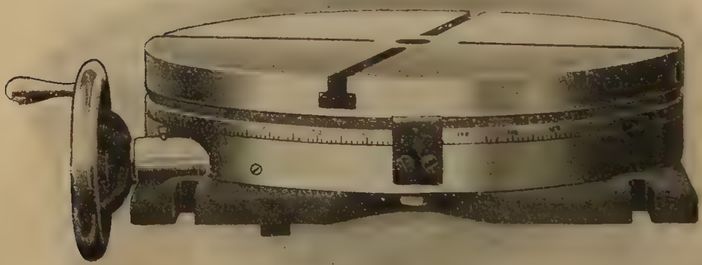


FIG. 247.—Rotary Table.

When a hole has been bored, both ends can be faced off without disturbing the work or the bar.

Vertical Boring Machines

There are few shops in which a vertical boring machine cannot be profitably employed, and a great deal of work which can only be machined on the lathe with difficulty, owing to the time and trouble involved in setting up, can be done on this type of machine. In its duplex form, as shown in Fig. 249, it is valuable for the rapid production of a wide range of work. The machine illustrated will swing work up to 26 in. in diameter, and is equipped with 18½ in. diameter chucks which will grip work up to 21 in. in diameter. In this machine the two tables are independently driven from separate countershafts, the four-speed cones in combination with the clutch-operated double gearing providing a range of eight speeds to each table. The gear changes, as well as the starting and stopping of the machine, are effected by the movement of the handles in front of the machine—one for each table. The whole of the driving gears have machine-cut teeth, and special provisions are made for the efficient lubrication of the driving shaft bearings, which are bushed with

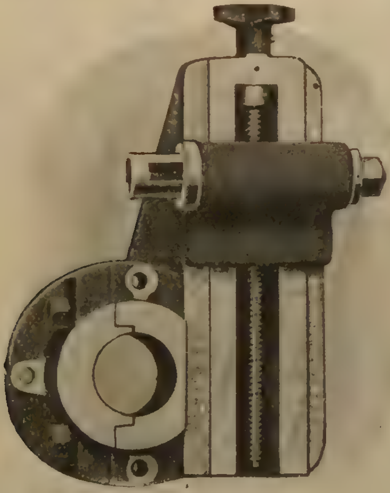


FIG. 248.—Star Feed Facing Attachment.

phosphor bronze. The top bearings of the hollow spindles are conical in form and run in adjustable taper bushes. Being driven by spur gears, there is no tendency on the part of the table to lift when taking heavy cuts.

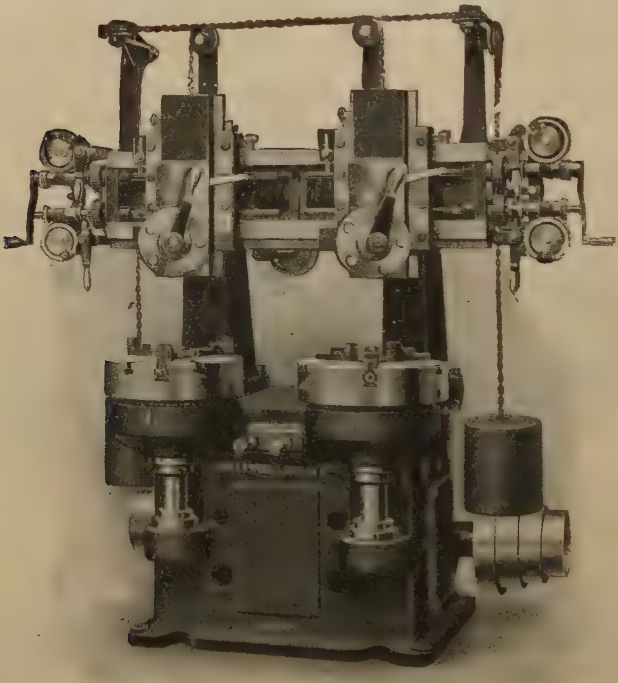


Fig. 249.—21-in. Duplex Boring Machine.

The automatic feeds of the turrets are entirely independent, and are driven by two-speed cone from the main drive through feed change gear box at the rear of the cross slide. A range of six rates of feed are provided to each turret in the horizontal and vertical directions, the gear changes being effected by the movement of a small lever operating a sliding key in the gear box, an index dial indicating the various rates of feed. Quick hand adjustments are also provided to the horizontal and vertical movements of the turret.

Independent and easily adjustable automatic trips are provided for the vertical and horizontal feeds of each turret, which can be set to trip the automatic feed at any predetermined point of the traverse. The automatic feed can also be disengaged by hand at any point without stopping the machine.

The turrets are bored to receive five tools, the latter being secured in position by steel clamping bolts. The turrets can be rigidly clamped to the saddle, eliminating vibration and ensuring rigidity while the tools are cutting, and provision is made for locating the turrets exactly central with the tables for boring or drilling operations. The turret slides are counterbalanced, and screw operated adjusting strips are fitted to both the saddles and cross slide to compensate for wear.

The base and upright are box section castings designed and proportioned to ensure strength and rigidity to the tables and cross slide. Removable covers in the base facilitate the inspection of the driving mechanism, etc.

Taper Turning

When it is necessary to machine on the boring mill a conical surface which has such a large included angle that the tool bar cannot be swivelled far enough to permit turning by the usual method, the combined vertical and horizontal feed are sometimes used to obtain the required taper. Suppose a conical casting is to be turned to an α of 30° (see Fig. 250), and that the tool head of the boring mill feeds horizontally $\frac{1}{4}$ in. per turn of the screw, and has a vertical movement of $\frac{3}{16}$ in. per turn of the vertical feed shaft. If the two feeds are used simultaneously with the tool bar at right angles to the table, the tool will move a distance h of 8 in., while it moves downwards a distance of 6 in., thus turning the surface to an angle β. This angle β is greater than the required angle ∝, but if the tool bar is swivelled to an angle γ, the tool, as it moves downwards, will be advanced horizontally in addition to the regular horizontal feeding movement. Hence, if the tool bar is set over to the proper angle γ, the surface can be turned to an angle ∝.

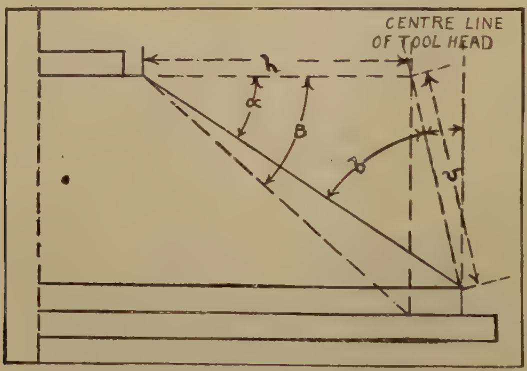


FIG. 250.—Diagram for Taper Turning.

The problem, then, is to determine what the angle γ should be for turning to a given angle ∝. Angle γ can be calculated as follows: Sin $b = \frac{\sin \propto \times h}{v}$, in which h represents the rate of horizontal feed and v the rate of vertical feed. Having angles ∝ and b, the desired angle γ is obtained by subtracting the sum of the former angles from 90°. To illustrate (using the values given in the foregoing), the sine of 30° is 0.5; then, sin $b = \frac{0.5 \times \frac{1}{4}}{\frac{3}{16}} = 0.6666$. Hence, angle $b = 41^\circ\ 48'$ and $\gamma = 90^\circ - (30 + 41^\circ\ 48') = 18^\circ\ 12'$. If angle $\propto$ were greater than angle β obtained from the combined feeds with the tool bar in the vertical position, it would be necessary to swing the lower end of the bar to the left rather than to the right of the vertical plane; that is, the lower end of the bar would be inclined to the left of the vertical an amount equal to the sum of the angles $\propto$ and b subtracted from 90°.

Boring and Turning Mill.—Fig. 251 illustrates a 48-in. machine in which the drive is transmitted through a speed box, rendering the machine self-contained, and therefore easily adaptable for motor drive. The table rests on a large conical seating, and the centre spindle runs in parallel bearings. A foot brake enables the operator to stop the table in any desired position.

The tool slides are provided with long bearings in the saddles, ensuring rigidity under heavy cuts. They are arranged to swivel 30° on each side of the vertical, and are counterbalanced in all positions. Independent automatic feed is provided to each slide, which may be accurately located in the central position. The tool-holders are securely held by three bolt pads. A spring device prevents the tool-holder from falling when the champing bolts are released for adjustment.

Fine adjustments of the tool can be obtained by cotters which are keyed to the free shafts and screws. The collars are turned by a small handle clearly seen in Fig. 251. The automatic feed to each slide is transmitted through a separate feed box, and therefore entirely independent. The feeds are changed by merely turning a hand wheel. Shearing pins are fitted to prevent any injury to the feed mechanism.

The rapid power traverse rapidly moves either tool slide in any direction. It is so arranged that the move-

RULES FOR FINDING TAPER.

Given	To Find	Rule.
The taper per inch - - -	The taper per foot - -	Multiply the taper per inch by 12.
The taper per foot - - -	The taper per inch - -	Divide the taper per foot by 12.
End diameters and length of taper in inches	The taper per foot - -	Subtract small diameters from large; divide by length of taper, and multiply quotient by 12.
The taper per foot - - -	Amount of taper in a certain length given in inches	Divide taper per foot by 12; multiply by given length of tapered part.
Small diameter and length of taper in inches, and taper per foot	Diameter at large end in inches	Divide taper per foot by 12; multiply by length of taper, and add result to small diameter.
Large diameter and length of taper in inches, and taper per foot	Diameter at small end in inches	Divide taper per foot by 12; multiply by length of taper, and subtract result from large diameter.
The taper per foot and two diameters in inches	Distance between two given diameters in inches	Subtract small diameter from large; divide remainder by taper per foot, and multiply quotient by 12.

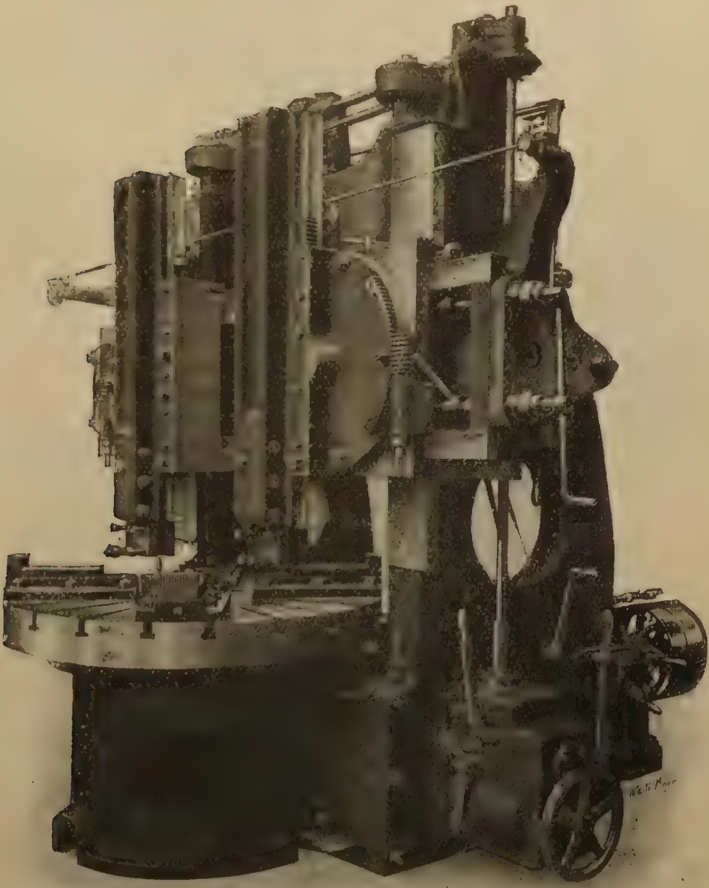


FIG. 251.—48-in. Vertical Boring and Turning Mill.

ment of the operating lever disengages the regular feed, and rapidly moves the slide in the opposite direction. It is also furnished to the cross slide for rapidly elevating or lowering.

Slotting Machines

The slotting machine illustrated at Fig. 252 is of modern design, and has been constructed to perform a greater variety of work than the ordinary slotting machine can do, and in a more convenient way. It is well known that the slotting machine is idle a great part of its time, as frequently there is not sufficient slotting work to keep it going. To obviate this a shaped attachment shown at Fig. 253, with a relief movement to the tool on the upward stroke, has been perfected, thus allowing large surfaces to be shaped, and keeping the machine in constant use. The tool in the shaped attachment can be swivelled to the right or left, and fixed by set plunger pin in each position.

The drive of the machine is by cut spur gearing and four-speed cone of large diameter and wide belt, a heavy solid fly wheel being fitted on the driving shaft.

The disc runs in a recess bored out in the main body of the casting, which relieves the strain of the cut on the driving shaft. The adjustment of the stroke in the disc is by a screw and nut running in a T slot, the same handle being used for setting the stroke and for adjusting the position of the ram. The longitudinal, transverse, and circular motions are all self-acting, and are engaged by positive clutches. Each feed or clutch can be engaged independently of the others.

The ram has a continuous bearing in the vertical slide and is counterbalanced. It is regulated in height by screw and bevel gears.

The ram slide can be swivelled 5° on each side for cutting taper keyways or for undercutting in die work. The ram is operated by link motion, which gives an even cutting speed and a quick return to the ram.

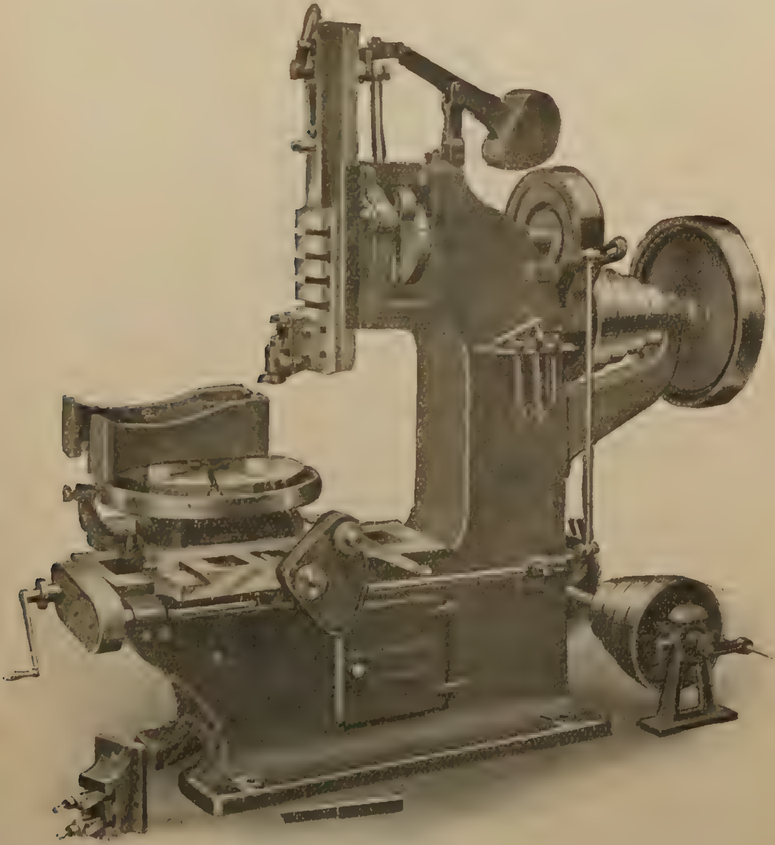


FIG. 252.—Combined Slotting and Vertical Shaping Machine.

The circular table is correctly indexed to 360°, and supplied with an index pointer; it has also twelve equally divided holes in the circumference, with an engaging spring plunger pin, so that work may be shaped on 2, 3, 4, 6, or 12 sides, all of these being positive positions. The table can be locked in any position, and is provided with a sud trough.

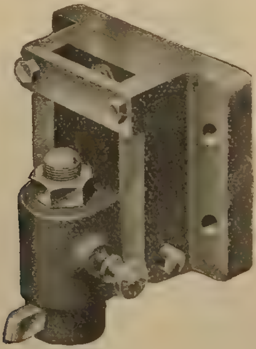


FIG. 253.—Shaping Attachment.

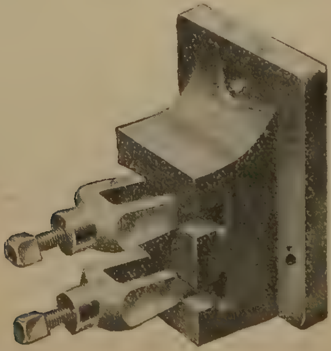


FIG. 254.—Extension Piece.

An extension piece used in conjunction with this machine is shown in Fig. 254.

CHAPTER XVIII

GEAR-HOBBING AND PLANING MACHINES

THE hobbing process of cutting gears is used to a very great extent in the modern engineering workshop. These machines will automatically generate spur and straight-face spiral gears and also worms. A wheel with perfect teeth would be one in which all the teeth were perfectly evenly spaced and correctly shaped, and it is impossible to obtain such teeth in a machine cutting only one tooth at a time; for this reason a hobbing machine, or a machine operating upon more than one tooth, is to be preferred for this class of work.

The most important point to aim at in hobbing wheels is to obtain as nearly as possible a perfect hob, and at the same time have a machine which is fully strong enough and quite rigid. The shafts carrying the wheels and hobs should also be of ample strength, because, if the hob shafts are weak, there is a liability for them to twist, thereby causing the hob to lag behind the work, the result being that a tooth will be cut in which one side is convex and the other concave.

Fig. 255 shows a machine for automatically generating spur and spiral gears, and also worms, by the use of parallel hobs. All gears of the same pitch can be cut by the same hob, giving correctly formed teeth independent of their number.

The machine is fitted with a dividing arrangement

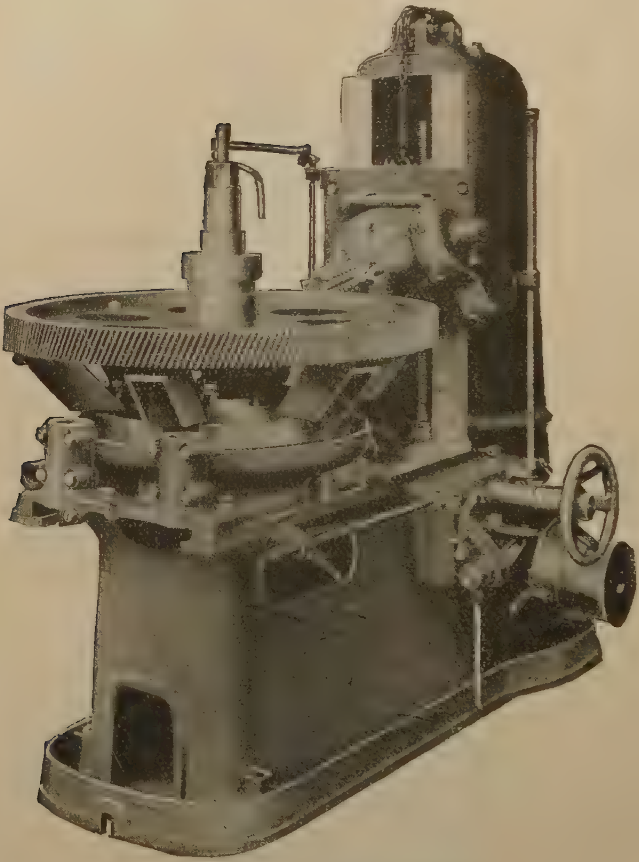


FIG. 255.—Gear-Hobbing Machine.

so that spur wheels may be cut with a single disc cutter, each tooth being divided by hand. This is very useful when a wheel of odd pitch has to be cut.

The Work Table is made of cast iron, with ample strength to resist all vibration. It has a large diameter bearing on the saddle with a deep central bearing, while lock nuts on the under side prevent any lifting tendency. The drive is through a hardened and ground worm and an accurately cut worm wheel, which are adjustable for wear. Ball-thrust washers are fitted to the worm.

The Saddle has a narrow guide and secure clamping device. It is provided with screw feed which may be operated either by hand or power. It is employed when cutting worm wheels, as the face of the blank is fed into the hob. A micrometer is provided for measuring the depth of tooth, and an automatic stop can be set to disengage the feed at the required depth of cut.

The continuous cut eliminates all troubles in dividing, and saves time which would otherwise be occupied by the idle return stroke of the cutters. Rigid support is given to blanks of large diameter and no uneven heating of the work, with consequent inaccuracy, is experienced. Better finished work is produced, and considerably less grinding of cutters is necessary, owing to the large number of teeth engaged at the same time.

The Work Arbors have taper ends which fit into a bracket on the table, and are secured with a large right and left hand nut. An efficient stay provides a rigid bearing to the upper end, but can be easily removed if desired.

Rapid Power Traverse is fitted for quickly setting the hob, or withdrawing it after completion of cut.

The Hob Saddle has a long bearing on the column with a narrow guide. It is counterbalanced, and has adjustment by means of a taper gib. Hand and automatic feed is provided, and an automatic trip can be set to disengage the feed at any desired point.

The Hob is driven by accurately cut double helical gearing and a powerful and steady drive is ensured, as the speed reduction is on the last pair of wheels. Six speeds in geometrical progression are obtained from the three-step cone and two-speed countershaft.

Fig. 256 illustrates a generating hob with spiral teeth, the pitch of the thread being equal to the pitch of the gear teeth being generated. The speed of rotation of both

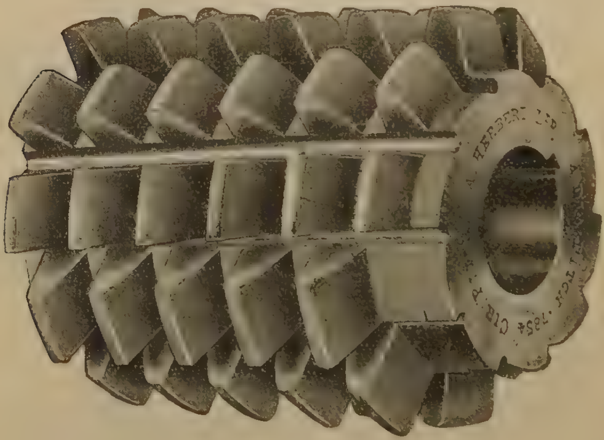


Fig. 256.—Hob for Generating Gears.

gear blank and hob are arranged to correspond, thus automatically ensuring correct dividing of the teeth and producing theoretically correct teeth. With this form of hob no calculation is required for the correct depth of the tooth, it being necessary to sink the hob into the blank until the periphery of the blank is just touching the bottom of the hob teeth.

Feeds for Hobbing.—The feeds for hobbing vary from about 0.02 to 0.2 in. per revolution of the gear. The following figures can be taken as approximate, and give the movement of the hob per revolution of the gear.

Material.	Feed.
Hard steel	0·01
Medium steel	0·03
Mild steel	0·04
Hard cast iron	0·03
Medium cast iron	0·05
Soft cast iron	0·15

When hobbing helical gears, the feed to some extent depends upon the angle of the teeth. Angles varying from 0°-36° can be cut about the same speed as spur gears; for angles from 36°-48°, the feed should be $\frac{4}{5}$ of that of spur gear; from 48°-60°, $\frac{2}{3}$ of that of spur gear; from 60°-70°, $\frac{1}{2}$ that of spur gear feed; for angles above 70°, $\frac{1}{3}$ of spur gear feed. The feed is diminished in the case of spiral gears, because when the hob is set to conform to the helix angle, the feed of the cutter, per revolution, is increased by the turning movement of the gear blank necessary for generating the helical teeth.

Change Gear for Spiral Gear-Hobbing Machines

The change gears to be used for generating spiral gears on gear-hobbing machines may be found by the following formula:—

$$\frac{L \div F}{(L \div F) \pm 1} \times \frac{P}{p} = \frac{S}{s},$$

in which

L = lead of spiral.
F = feed per revolution.
P = product of driving gear for cutting spur gears with the same number of teeth.
p = product of driven gears for cutting spur wheels with same number of teeth.
S = product of driving gears for cutting spiral gears.
s = product of driven gears for cutting spiral gears.

In the formula, use + sign when gear and hob are of opposite ‘hand,” and – sign when they are of the same “hand.”

Example.—Two spiral gears are to be cut on a gear-hobbing machine. Gear No. 1 has 30 teeth, 24.549 in. lead, and a feed of $\frac{1}{24}$ in. The change gears used on the machine for cutting a spur gear with 30 teeth have 48 driving gear and 60 driven gear. The hob and gear are of the same “hand.” Gear No. 2 has 60 teeth, 49.098 lead, with a feed of $\frac{1}{16}$ in. Change gears used to cut a spur gear with 60 teeth, on this machine, have 48 and 40 teeth for the driving gears and 60 and 80 for the driven gears. The hob and gear are of the same “hand.”

The data then is :—

30 Tooth Gear.		60 Tooth Gear.	
L - - - -	24·549	L - - - - -	49·098
F - - - -	$\frac{1}{24}$	F - - - -	$\frac{1}{16}$
P - - - -	48	P - - - -	40×48
p - - - -	60	p - - - -	60×80

Calculations for Thirty Tooth Gear

By inserting the values given :—

$$\frac{L \div F}{(L \div F) - 1} = \frac{589 \cdot 176}{588 \cdot 176}$$

the above ratio can be simplified to the form—

$$\frac{589}{588} \text{ and by factoring to } \frac{19 \times 31}{12 \times 49}.$$

Now, multiply this value with the ratio of the gear for a 30 tooth spur gear—

$$\frac{19 \times 31}{12 \times 49} \times \frac{48}{60} = \frac{76 \times 31}{60 \times 49}.$$

Having obtained the gears, investigate what lead the gears will give. As an approximate ratio was used instead of the real one, an approximate lead will only be obtained. To prove—

Assume $F = \frac{1}{24}$ and solve for L—

$$\frac{L \div F}{(L \div F) - 1} = \frac{589}{588}.$$

From this L = 24.541, which is nearly equal to the required lead.

The calculations for the 60 tooth gear are carried out in exactly the same manner as for the 30 tooth gear.

Bevel Wheel Shaping Machine

Fig. 257 illustrates a bevel wheel shaping machine of modern design.

The Work Spindle.—The headstock carrying the work spindle and automatic dividing mechanism is adjustable on the face of the smaller of two superimposed swivelling sectors, to suit wheels of varying diameter. The gear blanks are mounted on a mandrel, which is secured by a draw-in rod. The adjustment of the smaller sector on the face of the larger enables the gear to be set to the correct angle, and this adjustment is effected by hand wheel operating worm gearing, as shown by the illustrations. An arbor support is included in the equipment of the larger machine, which, when fitted in position to the central pivot of the swivelling sectors, rigidly supports the outer end of arbor.

The Formers.—As is shown by the illustration, the former from which the shape of tooth is reproduced is carried at the extreme end of a radial bar, the latter being adjustable in the socket by which it is carried, so that the height of the former may be regulated to suit the work under operation. The former is kept in proper contact with the hardened steel guide plate by a suspended weight, the guide pulleys being attached to the sliding bracket in which the guide plates (one for each side of the tooth) are held.

Automatic Feed and Trip.—The feed of the work towards the reciprocating cutting tool is automatic and easily variable. It is effected by the radial adjustment of the large sector, driven by a crank disc having an adjustable stroke, ratchet mechanism, and worm gearing,

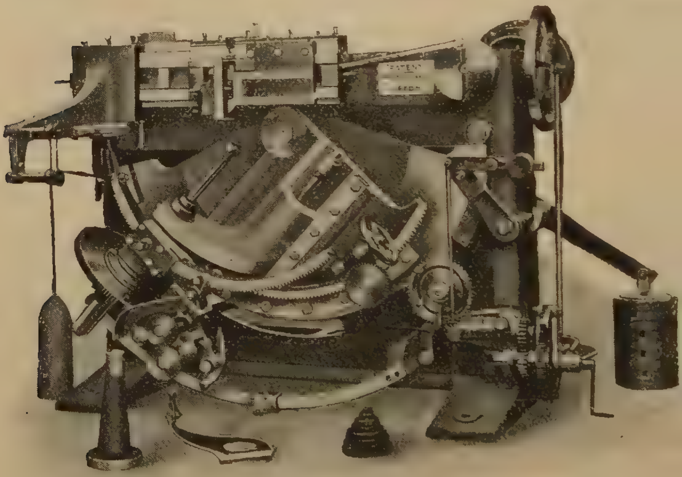


FIG. 257.—Bevel Wheel Shaping Machine.

a pinion engaging with the teeth cut in the periphery of the large swivelling sector. As the wheel being cut is automatically fed towards the reciprocating tool, the work spindle receives an axial motion imparted to it from the copy or former. With the feed mechanism is combined an automatic trip, which, by the adjustment of the dog in the annular grove of the worm wheel, can be set to automatically disengage the feed as soon as the tooth has been cut to the desired depth. The disengagement of the feed mechanism allows the sector (which is counterbalanced) to return to its original position ready for the commencement of the next tooth, when the feed is automatically re-engaged.

Dividing Mechanism.—The dividing mechanism operates automatically, and is driven by a pulley at the rear of the machine, through friction disc and change gears, and controlled by a locking cam, which is released on the return movement of the sector, a trip lever operating against an adjustable stop carried on the radial bar near the bottom of the machine. At the completion of the dividing operation, the mechanism is automatically locked with the gear in correct position for the cutting of the succeeding tooth.

The Tool Slide.—The tool box is carried on a slide having a reciprocating movement, driven by a crank disc by which the length of stroke can be varied to suit the gear to be cut. Three changes of speed are provided by the driving cone. The bearing surfaces of the slide are of ample proportions, efficiently lubricated, and any necessary adjustment can be effected by screw operated gibs.

The tool box, which has vertical, horizontal, and angular adjustments, is hinged to prevent rubbing of the tool on the return stroke. The cutting tools are simple in form, easy to make, and cheaply renewed.

Gear Planers

A machine for planing the teeth of spur, chain, and spiral gears is illustrated at Fig. 258. The drive of the machine is by means of a belt from a three-step cone on a countershaft, and changes of speed are obtained by cone pulleys and gear change by lever, six rates of speed being available. The cutter slide has a quick return motion from a worm-driven crank disc, and is set to cut obliquely or at an angle across the face of the blanks when cutting spirals.

The cutter box for holding the cutter may be set at varying positions to suit the position of the wheel blank. The thrust of the cutter, except on small wheels, is taken by an adjustable rim stay, and two lengths of outer supports for the arbor are provided for use when the rim stay cannot be applied.

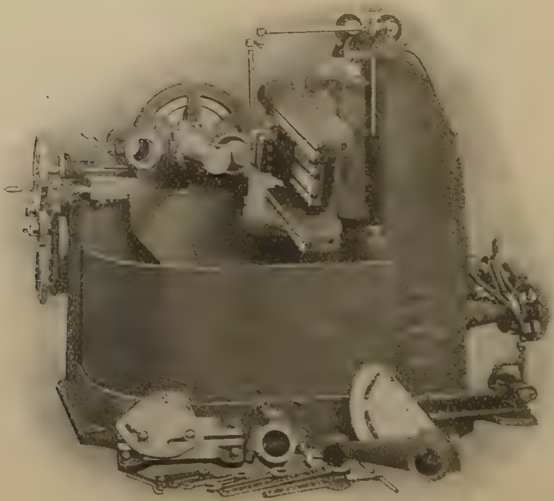


FIG. 258.—Gear Planing Machine.

Gear blanks are usually mounted on an arbor secured in the spindle socket, and the dividing wheel is securely fixed to the spindle, but the dividing worm may be disengaged and the spindle rotated freely, to test the tooth of the arbor or blank.

The feed motion, driving through one shaft, causes simultaneously and in unison, the rotary motion of the blank and the travel of the cutter, for a distance of one, two, or more pitches according to circumstances, whereupon the gear blank withdraws from the cutter, which returns to its original position, in order to operate on the next or succeeding segments of the gear blank, which then re-engages the cutter. These movements repeated complete the gear. The feed operates intermittently on the

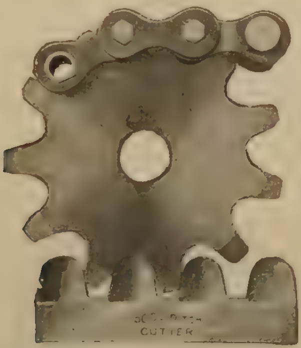


FIG. 259.—Wheel Cutter.

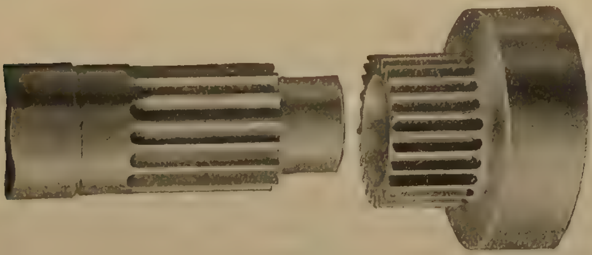


FIG. 260.—Cut Gears.

return stroke of the cutter, and thus, during the cutting stroke, the dividing wheel and worm are at rest and not wearing. The rate of feed may be varied while running by a conveniently placed quick-change lever.

The process of cutting the teeth is a generative one, and has some of the advantages of hobbing. The involute system of tooth form is based on a rack, and the basis of the "Sunderland" planing system is using a rack as a cutter, and imparting to the cutter and gear the same relative motion as a rack and gear wheel. The rack cutter operates directly on the gear, and one cutter will cut all numbers of teeth of the same pitch.

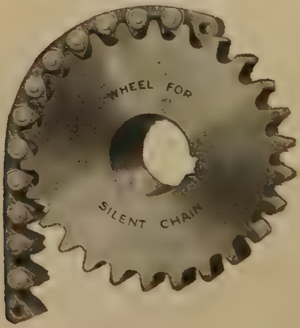


Fig. 261.—Cut Gear.

The action of the cutter is shown in Fig. 259; it will be seen that several teeth are in contact at the same time. The generative action is produced by traversing the cutter exactly like a rack, at a tangent to the pitch circle of the gear as it rotates, and exactly at the same speed. Figs. 260 and 261 show examples of work done by this type of machine.

CHAPTER XIX

TOOL-HOLDERS

The advantages of tool-holders over the solid type of machine tool are:—

1. The facility with which the cutting edge of the tool can be adjusted to its correct height.

2. The ease with which the cutting tool itself can be removed and replaced.

3. The small amount of expensive tool metal required.

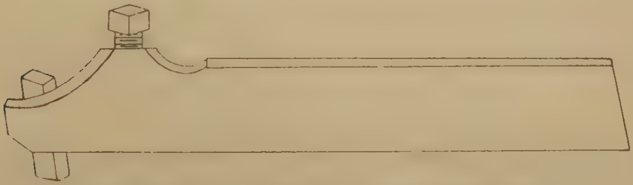


Fig. 262.—Tool-Holder for Square Section Steel.

The cost of modern high-speed steel, and of alloys such as are used in the manufacture of stellite, prohibits the use of solid tools, especially those of heavy section.

Many of the best cutting steels are extremely brittle, and, if held in any other manner than by means of a tool-holder, will frequently crack in the body of the tool.

A good type of tool-holder is undoubtedly a means of saving money and time, and its use is strongly to be recommended in conjunction with the best quality of high-speed cutting metal.

A simple form of tool-holder is illustrated in Fig. 262.

This type of holder will be found very useful for holding square section tools "on end." It has been found particularly useful for gripping stellite, as, when used in this position, the very hard scale of the alloy is presented to the surface of the work where the rubbing takes place. It allows the tool to be easily ground to the desired top and side rake, and also adjusted for height. When adjusting the tool for height, the small set-screw at the top is slacked back, and the tool is pushed into position; on tightening up the set-screw, the tool is firmly held by means of a wedge-piece, which effectually prevents the tool from moving.

It may be mentioned here that stellite is an extremely hard metal composed chiefly of cobalt and chromium. It cannot be hardened, and heat has no effect on its cutting qualities until a temperature of 1,000° F. is reached. It is cast into a variety of shapes, and can be reduced in size only by grinding. For most purposes the square section is suitable, and either of the tool-holders shown in Figs. 262 and 263 can be used. The holder shown in Fig. 263, known as the Weston holder, not only affords the maximum support to the cutter through the projecting lip and the cutter nose, but also provides the necessary amount of top rake. This feature is particularly desirable, as it tends to maintain unimpaired the exceptional cutting properties of stellite just where it is most wanted, namely, at the top surface of the cutter.

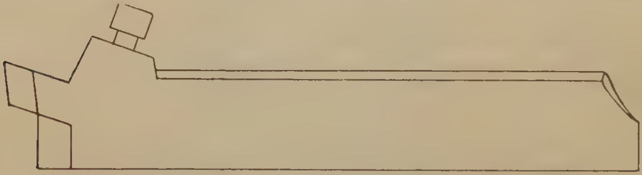


FIG. 263.—The "Weston" Tool-Holder.

A right-hand side tool-holder for square section tools is

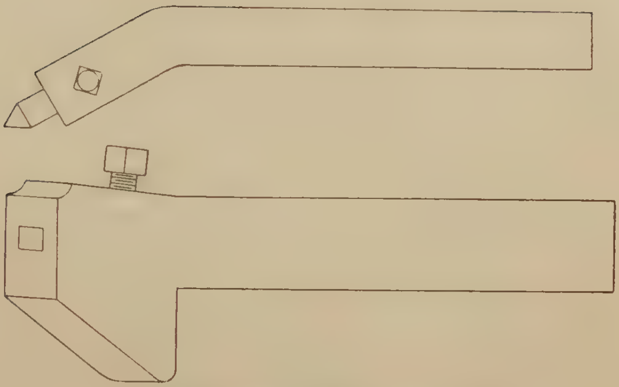


FIG. 264.—Right Hand Side Tool-Holder

shown in Fig. 264. The front part of this type of holder is set either to the right or left as desired, and the tool is held in position by the direct pressure of the set-screw. This type of holder is very suitable for heavy work.

Swivel Holders

A three-way swivel tool-holder is shown in Fig. 265. This is usually fitted with square section tools, and takes

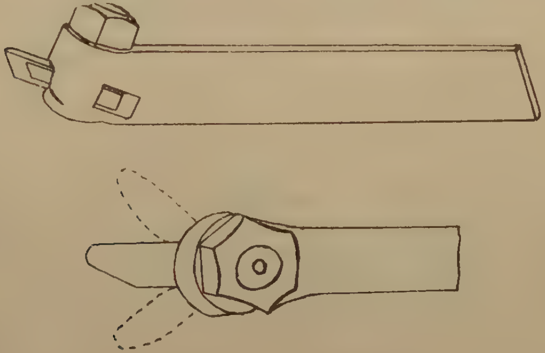


FIG. 265.—Three-Way Tool-Holder.

the place of three ordinary tool-holders. It can be adjusted for right-hand, left-hand, or straight turning. The cutter is locked in any of the positions, and the tool post, which sets at an angle with the body, gives the proper rake. When in the off-set position, owing to the angle of the tool post, the cutting edge is raised, giving an additional side rake which obviates the necessity of grinding a lip on the cutter. This holder is made of drop forged steel, afterwards case-hardened, and is known as the "Carr" three-way tool-holder.

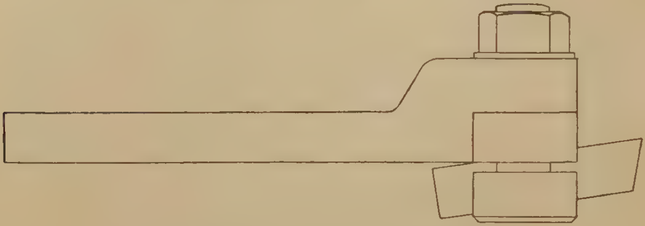


FIG. 266.—Swivel Tool-Holder.

Another type of three-way tool-holder is shown in Fig. 266. This holder takes a V section tool only, and is intended for use in planing and shaping machines as well as in lathes. The cutter itself can be shaped for screw-cutting, parting off, or any other form of tool.

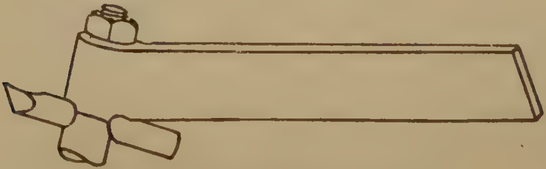


FIG. 267.—Swivel Tool-Holder.

A simple type of swivel tool-holder suitable for comparatively light work is illustrated in Fig. 267. In this case the section of the tool is round, and suitable semicircular slots are provided to allow the tool to be held in the various positions.

Screw-Cutting Tool-Holders

The tool-holder shown in Fig. 268 is intended to hold a special form of thread cutter. The tool is ground on the cutting edge to the correct angle. It can be rotated on the pin provided, and can be adjusted for height, when necessary, by means of a screw. This holder allows of the use of a simple and effective cutter for V threads.

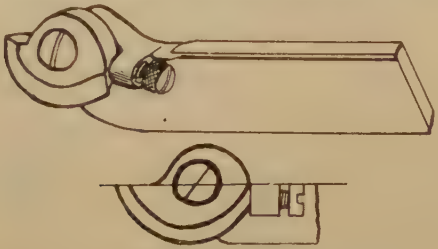


FIG. 268.—Screw Thread Tool-Holder.

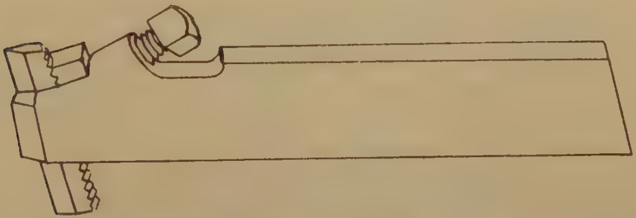


FIG. 269.—Holder for Screw-Cutting Tool.

A different type of screw-thread tool-holder is shown in Fig. 269. The cutter is of special shape, the back part being serrated in order that a loose piece, similarly serrated, may be able to hold it firmly in position.

An improved type of holder is illustrated in Fig. 270. The tool in this case is suitably serrated at the side, and is held in position by means of a loose clamp. The holder is made similar in shape to a spring tool, and therefore it is possible to take fine cuts and give a good finish to the thread being cut. It is usual with this type of tool to use a different cutter for each different pitch. The cutters are specially made, so that when the cut is taken to the correct depth the top of the thread is rounded off to the required amount.

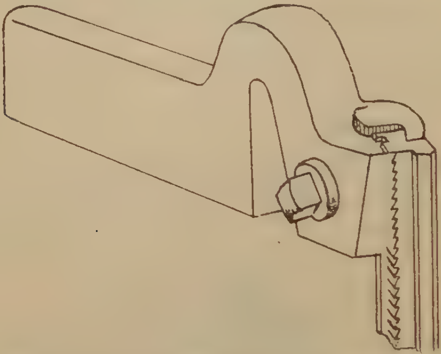


FIG. 270.—Spring Tool-Holder for Screw-Cutting Tools.

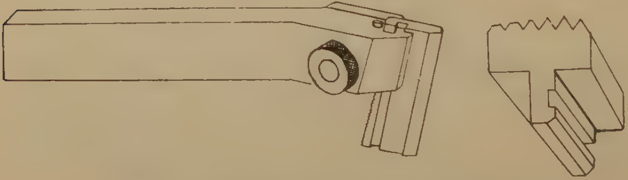


FIG. 271.—Tool-Holder for Thread Chasers.

Fig. 271 shows still another type of screw-thread tool-holder, which will be found to give satisfaction as the tool is firmly held. For finishing threads, a form of chaser is used similar to that shown in the illustration, but conforming to the pitch and standard required.

Parting-Off Tool-Holders

With the ordinary type of parting tool made from solid bars, the percentage of breakages is very high, and therefore with this particular tool the tool-holder principle is most economical and at the same time very effective. Fig. 272 illustrates an off-set parting tool-holder. The blades are usually made from high-grade self-hardening steel, and are bevelled on both sides, thus giving the proper clearance to ensure a clean-cutting tool.

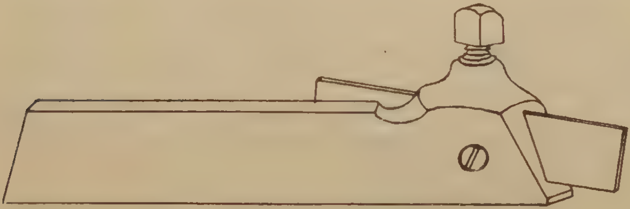


FIG. 272.—Parting-Off Tool-Holder.

Boring Tool-Holders

A very simple form of boring bar tool-holder for samll work is illustrated in Fig. 273. Here the holder simply

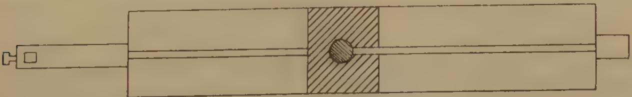


FIG. 273.—Tool-Holder for Boring Tool.

consists of a piece of oblong or square section steel, bored out, and slotted at one side. A boring bar of suitable size is used, and this is held in position by the holding-down dogs of the tool-holder.

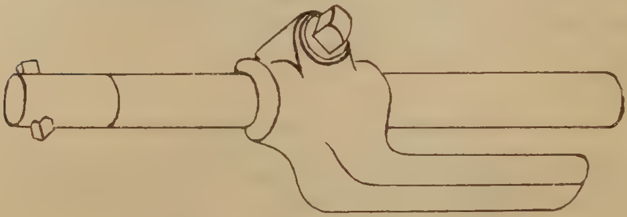


FIG. 274.—Tool-Holder for Boring Bar.

Fig. 274 shows another simple and effective type of holder. This consists of a forging bored out to take the bar, and one side of it is split in order that the bar can be gipped when the set screw is tightened down.

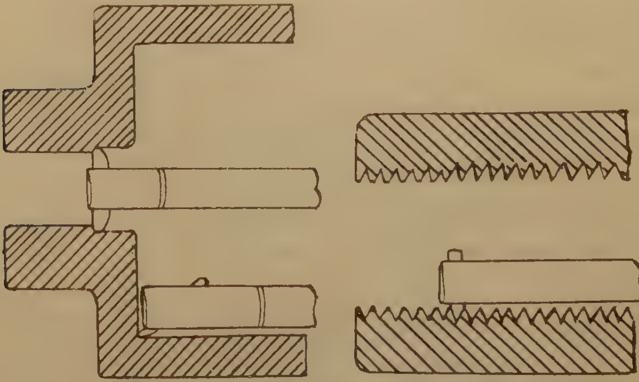


FIG. 275.—Examples of One Use of Boring Bar.

Illustrations showing the use of the tool bar, and the form the cutters take, are given in Fig. 275. Boring tools afford another example of the specially economical effect of using tool-holders. They save the time taken for regrinding tools by the machine hand and prevent machines from standing idle.

Combined Turning and Boring Tool-Holder

A combined turning and boring tool-holder is shown in Fig. 276. When using the turning tool, an adjustment can be made by means of a small set-screw at the back. The boring tool is of round section, and when necessary can be turned to give the desired clearance.

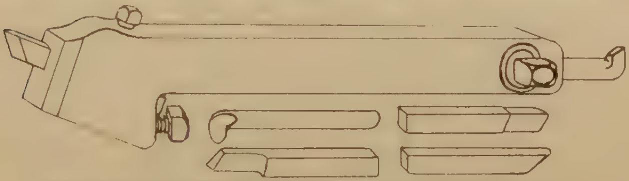


FIG. 276.—Combined Turning and Boring Tool-Holder.

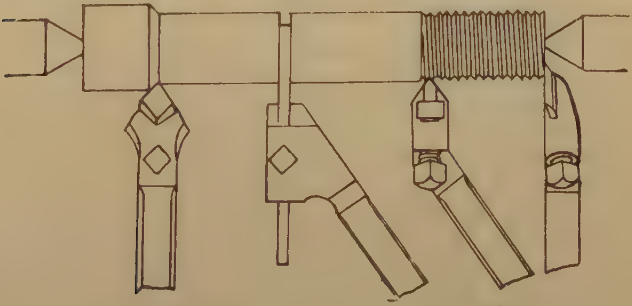


FIG. 277—Application of Variour Tool-Holders.

Tool-holders of various kinds are illustrated in Fig. 277. The tools are shown in position for facing, screw-cutting, parting, and turning.

Tables

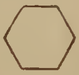
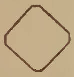
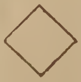
WHITWORTH STANDARD BOLTS AND NUTS

(*Dimensions are given to the nearest 1/64 in.*)

Diam. of Bolts.	Bolt Head and Nuts.						Threads per Inch.	Pitch in Inches.	Diameter of Tapping Hole.	
	Width across Flats.		Width across Corners.		Height of Bolt Head.					
In.	In.	In.	In.	In.	In.	In.			In.	In.
3/16	7/16		1/2	and 1/64	1/8	and 1/32	24	0·041	1/8	and 1/64
1/4	1/2	and 1/64	9/16	,, 3/64	3/16	,, 1/32	20	0·050	3/16	
5/16	9/16	,, 3/64	11/16		1/4	,, 1/64	18	0·055	1/4	
3/8	11/16	,, 1/64	13/16		5/16	,, 1/64	16	0·0625	1/4	,, 3/64
7/16	13/16	,, 1/64	15/16	,, 1/64	3/8		14	0·071	5/16	,, 3/64
1/2	7/8	,, 1/32	1 1/16		7/16		12	0·083	3/8	,, 1/32
9/16	1	,, 1/64	1 1/8	,, 1/32	7/16	,, 3/64	12	0·083	7/16	,, 1/32
5/8	1	,, 3/32	1 1/4	,, 1/64	1/2	,, 3/64	11	0·091	1/2	,, 1/64
11/16	1 3/16	,, 1/64	1 3/8	,, 1/64	9/16	,, 1/32	11	0·091	9/16	,, 1/64
3/4	1 1/4	,, 3/64	1 1/2		5/8	,, 1/32	10	0·100	5/8	
13/16	1 3/8	,, 1/64	1 9/16	,, 1/32	11/16	,, 1/64	10	0·100	11/16	
7/8	1 7/16	,, 3/64	1 11/16	,, 1/64	3/4	,, 1/64	9	0·111	11/16	,, 3/64
15/16	1 9/16	,, 1/64	1 13/16	,, 1/64	13/16		9	0·111	3/4	,, 3/64
1	1 5/8	,, 3/64	1 15/16	,, 1/64	7/8		8	0·125	13/16	,, 1/32
1 1/8	1 13/16	,, 3/64	2 1/8	,, 1/32	15/16	,, 3/64	7	0·143	15/16	,, 1/64
1 1/4	2	,, 3/64	2 5/16	,, 3/64	1 1/16	,, 1/32	7	0·143	1 1/16	
1 3/8	2 3/16	,, 1/32	2 1/2	,, 3/64	1 3/16	,, 1/64	6	0·166	1 1/8	,, 3/64
1 1/2	2 3/8	,, 1/32	2 3/4	,, 1/32	1 5/16		6	0·166	1 1/4	,, 3/64
1 5/8	2 9/16	,, 1/64	2 15/16	,, 1/32	1 3/8	,, 3/64	5	0·200	1 3/8	
1 3/4	2 3/4		3 3/16		1 1/2	,, 1/32	5	0·200	1 1/2	
1 7/8	3 1/16		3 7/16	,, 3/64	1 5/8	,, 1/64	4 1/2	0·222	1 9/16	,, 1/32
2	3 1/8	,, 1/32	3 5/8		1 3/4		4 1/2	0·222	1 11/16	,, 1/32
2 1/4	3 1/2	,, 3/64	4 1/16	,, 1/32	1 15/16	,, 1/32	4	0·250	1 15/16	
2 1/2	3 7/8	,, 1/64	4 7/16	,, 3/64	2 3/16		4	0·250	2 3/16	
2 3/4	4 3/16		4 13/16	,, 1/64	2 3/8	,, 1/32	3 1/2	0·285	2 3/8	,, 1/32
3	4 1/2	,, 1/32	5 3/16	,, 3/64	2 5/8		3 1/2	0·285	2 5/8	,, 1/64
3 1/4	4 13/16	,, 3/64	5 9/16	,, 1/32	2 13/16	,, 1/64	3 1/4	0·307	2 13/16	,, 3/64
3 1/2	5 1/8	,, 3/64	5 15/16	,, 3/64	3 1/16		3 1/4	0·307	3 1/8	
3 3/4	5 1/2	,, 3/64	6 3/8	,, 1/32	3 1/4	,, 1/32	3	0·333	3 5/16	,, 1/64
4	5 15/16	,, 1/64	6 7/8		3 1/2		3	0·333	3 9/16	,, 1/64
4 1/4	6 3/8		7 5/16	,, 3/64	3 11/16	,, 1/64	2 7/8	0·348	3 3/4	,, 3/64
4 1/2	6 13/16	,, 1/64	7 7/8		3 15/16		2 7/8	0·348	4	,, 3/64
4 3/4	7 1/4	,, 3/64	8 7/16		4 1/8	,, 1/32	2 3/4	0·364	4 1/4	,, 1/32
5	7 3/4	,, 3/64	9	,, 1/64	4 3/8		2 3/4	0·364	4 1/2	,, 1/32
5 1/2	8 13/16	,, 1/32	10 3/16	,, 1/32	4 13/16		2 5/8	0·381	5	,, 1/64
6	10		11 1/2	,, 3/64	5 1/4		2 1/2	0·400	5 7/16	,, 3/64

SQUARES AND HEXAGONS

Dimensions across Flats and Corners

Across Flats.			
1/4	·29	·33	·36
5/16	·36	·41	·44
3/8	·43	·50	·53
7/16	·50	·58	·62
1/2	·57	·66	·71
9/16	·65	·75	·80
5/8	·72	·83	·88
11/16	·79	·91	·97
3/4	·86	1·00	1·06
13/16	·93	1·08	1·15
7/8	1·01	1·16	1·24
15/16	1·08	1·25	1·33
1	1·15	1·33	1·41
1 1/16	1·22	1·42	1·50
1 1/8	1·29	1·50	1·59
1 3/16	1·37	1·58	1·68
1 1/4	1·44	1·66	1·77
1 5/16	1·51	1·75	1·86
1 3/8	1·58	1·83	1·94
1 7/16	1·66	1·92	2·03
1 1/2	1·73	2·00	2·12
1 9/16	1·80	2·08	2·21
1 5/8	1·88	2·16	2·30
1 11/16	1·95	2·25	2·39
1 3/4	2·02	2·33	2·47
1 13/16	2·09	2·42	2·56
1 7/8	2·17	2·50	2·65
1 15/16	2·24	2·58	2·74
2	2·31	2·66	2·83

Flats of Hex. × 1·55 = Corners.
,, Square × 1·414 = ,,

WEIGHT PER FOOT OF ROUND AND SQUARE BAR IRON

Inch.	Round.	Square.	Inch.	Round.	Square.
¼	·165	·211	4	42·464	54·084
⅜	·373	·475	4¼	47·952	61·055
½	·663	·845	4½	53·760	68·448
⅝	1·043	1·320	4¾	59·900	72·264
¾	1·493	1·901	5	66·350	84·480
⅞	2·032	2·588	5¼	73·172	93·168
1	2·654	3·380	5½	80·304	102·24
1⅛	3·360	4·278	5¾	87·776	111·75
1¼	4·147	5·280	6	90·525	121·66
1⅜	5·019	6·390	6¼	103·70	132·04
1½	5·972	7·604	6½	112·16	142·81
1⅝	7·010	8·926	6¾	120·96	154·01
1¾	8·128	10·352	7	130·04	165·63
1⅞	9·333	11·883	7¼	139·54	177·67
2	10·616	13·520	7½	149·32	190·13
2¼	13·440	17·112	7¾	159·45	203·02
2½	16·588	21·120	8	169·85	216·33
2¾	20·076	25·560	8¼	180·69	230·06
3	23·888	30·416	8½	191·80	244·22
3¼	28·040	35·704	8¾	203·26	258·80
3½	32·512	41·408	9	215·04	273·79
3¾	37·332	47·534	9¼	227·15	289·22

WEIGHT OF FLAT BAR IRON PER LINEAL FOOT

Width.	Thickness in Fractions of Inches.								
	¼	5/16	⅜	7/16	½	⅝	¾	⅞	1
1	·84	1·05	1·26	1·48	1·69	2·11	2·53	2·95	3·38
1⅛	·95	1·18	1·42	1·66	1·90	2·37	2·85	3·32	3·80
1¼	1·05	1·32	1·58	1·85	2·11	2·64	3·17	3·69	4·22
1⅜	1·16	1·45	1·74	2·03	2·32	2·90	3·48	4·06	4·64
1½	1·26	1·58	1·90	2·22	2·53	3·17	3·80	4·43	5·07
1⅝	1·37	1·71	2·06	2·40	2·74	3·43	4·12	4·80	5·49
1¾	1·48	1·85	2·22	2·59	2·95	3·69	4·43	5·17	5·91
1⅞	1·58	1·98	2·37	2·77	3·17	3·96	4·75	5·54	6·33
2	1·69	2·11	2·53	2·96	3·38	4·22	5·07	5·91	6·76
2¼	1·90	2·37	2·85	3·33	3·80	4·75	5·70	6·65	7·60
2½	2·11	2·64	3·17	3·69	4·22	5·28	6·33	7·39	8·45
2¾	2·32	2·90	3·48	4·07	4·65	5·81	6·97	8·13	9·29
3	2·53	3·17	3·80	4·43	5·07	6·34	7·60	8·87	10·14
3¼	2·74	3·43	4·12	4·80	5·49	6·86	8·24	9·61	10·98
3½	2·96	3·69	4·43	5·17	5·91	7·39	8·87	10·35	11·83
3¾	3·17	3·96	4·75	5·54	6·33	7·92	9·50	11·09	12·67
4	3·38	4·22	5·07	5·91	6·76	8·45	10·14	11·83	13·52

TABLE OF CONVERSION FACTORS

English to Metrical

Pounds per lineal foot - × 1·488 = kilos. per lineal metre.
Pounds per lineal yard - × 0·496 = kilos. per lineal metre.
Tons per lineal foot - × 3333·33 = kilos. per lineal metre.
Tons per lineal yard - × 1111·11 = kilos. per lineal metre.
Pounds per mile - - × 0·2818 = kilos. per lineal metre.
Pounds per square inch - × 0·0703 = kilos. per square centimetre.
Tons per square inch - × 1·575 = kilos. per square millimetre.
Pounds per square foot - × 4·883 = kilos. per square metre.
Tons per square foot - × 10·936 = tonnes per square metre.
Tons per square yard - × 1·215 = tonnes per square metre.
Pounds per cubic yard - × 0·5933 = kilos. per cubic metre.
Pounds per cubic foot - × 16·020 = kilos. per cubic metre.
Tons per cubic yard - × 1·329 = tonnes per cubic metre.
Grains per gallon - - × 0·01426 = grammes per litre.
Pounds per gallon - - × 0·09983 = kilos. per litre.
Gallons per square foot - × 48·905 = litres per square metre.
Foot-pounds - - × 0·1382 = kilogrammetres.
Foot-tons - - - × 0·3333 = tonne-metres.
Horse power - - × 1·0139 = force de cheval.
Pounds per H.P. - - × 0·477 = kilos. per cheval.
Square feet per H.P. - × 0·0196 = square metre per cheval.
Cubic feet per H.P. - × 0·0279 = cubic metre per cheval.
Heat units - - - × 0·252 = calories.
Heat units per square foot - × 2·713 = calories per square metre.

Table of Conversion Factors—*contd.*

Metrical to English

Kilos. per lineal metre -	×	0·672	=pounds per lineal foot.
Kilos. per lineal metre -	×	2·016	=pounds per lineal yard.
Kilos. per lineal metre -	×	0·0003	=tons per lineal foot.
Kilos. per lineal metre -	×	0·0009	=tons per lineal yard.
Kilos. per lineal metre -	×	3·548	=pounds per mile.
Kilos. per square centimetre	×	14·223	=pounds per square inch.
Kilos. per square millimetre	×	0·635	=tons per square inch.
Kilos. per square metre -	×	0·2048	=pounds per square foot.
Tonnes per square metre -	×	0·0914	=tons per square foot.
Tonnes per square metre -	×	0·823	=tons per square yard.
Kilos. per cubic metre -	×	1·686	=pounds per cubic yard.
Kilos. per cubic metre -	×	0·0624	=pounds per cubic foot.
Tonnes per cubic metre -	×	0·752	=tons per cubic yard.
Grammes per litre - -	×	73·09	=grains per gallon.
Kilos. per litre - -	×	10·438	=pounds per gallon.
Litres per square metre -	×	0·0204	=gallons per square foot.
Kilogrammetres - -	×	7·233	=foot-pounds.
Tonne-metres - -	×	3·000	=foot-tons.
Force de cheval - -	×	0·9863	=horse-power.
Kilos. per cheval - -	×	2·235	=pounds per H.P.
Square metre per cheval -	×	10·913	=square foot per H.P.
Cubic metre per cheval -	×	35·806	=cubic feet per H.P.
Calories - - -	×	3·986	=heat units.
Calories per square metre -	×	0·369	=heat units per square foot.

METRIC WEIGHTS AND MEASURES

Approximate Equivalents

1 millimetre ($\frac{1}{1000}$ metre) = ·03937 or $\frac{1}{25}$ inch.
1 centimetre ($\frac{1}{100}$ metre) = ·3937 inch.
1 decimetre ($\frac{1}{10}$ metre) = 3·937 inches.
1 metre = 39·37 inches or $1\frac{1}{11}$ yards.
1 kilometre (1,000 metres) = ·621 or $\frac{5}{8}$ English mile.
1 gramme = 15·43 grains.
1 kilogramme = 2·2046 lbs.
1 millier (metric ton) = 1,000 kilos. (2,204·62 lbs.).
1 litre = 1·761 (2·201 lbs.).
100 litres = 22 imp. gallons.
1 inch = 25·4 millimetres ($2\frac{1}{2}$ cm.).
1 foot = ·3048 metre.
1 yard = ·9144 metre.
1 mile = 1·609 kilometres.
1 lb. = ·4536 kilo.
1 cwt. = 50·80 kilos.
1 ton = 1016·40 kilos.
1 gallon = 4·546 litres (10 lbs.).
1 square inch = $6\frac{1}{2}$ square centimetres.
1 square centimetre = ·155 square inch.
1 square yard = $\frac{6}{7}$ square metre.
1 square metre = $10\frac{3}{4}$ sq. ft. or $1\frac{1}{5}$ sq. yards.
1 cubic foot = 28·3 litres (62·5 lbs.).
(28·35 kilos.).
1 cubic yard = $\frac{3}{4}$ cubic metre.
1 cubic metre = $1\frac{1}{3}$ cubic yards.

To Convert

Lbs. into kilos × ·453493.
Kilos. into lbs. × 2·20462.
Lbs. per square inch × ·0703 = kilos. per square cm.
Kilos. per square cm. × 14·223 = lbs. per square inch.
Inches into millimetres × 25·39977.
Millimetres into inches × ·03937043.
Square feet into square metres × ·0929013.
Square metres into square feet × 10·7641.
Gallons into litres × 4·54102.
Litres into gallons × ·220215.
English horse power into French force de cheval × 1·01386.
French force de cheval into English horse power × ·98633.

TABLE OF HELIX ANGLES

Giving the Setting Angles of Milling Machines, Twist Drill Flute Milling Machine Heads, etc.

Lead. / Diam.	Helix Angle.	Lead. / Diam.	Helix Angle.	Lead. / Diam.	Helix Angle.	Lead. / Diam.	Helix Angle.
2·00	57° 31′	5·20	31° 8′	8·75	19° 45′	20·00	8° 56′
2·20	55° 0′	5·40	30° 11′	9·00	19° 15′	25·00	7° 10′
2·40	52° 37′	5·60	29° 18′	9·50	18° 18′	30·00	5° 59′
2·60	50° 23′	5·80	28° 27′	10·00	17° 27′	35·00	5° 7′
2·80	48° 16′	6·00	27° 38′	10·50	16° 39′	40·00	4° 29′
3·00	46° 19′	6·20	26° 52′	11·00	15° 56′	50·00	3° 36′
3·20	44° 28′	6·40	26° 9′	11·50	15° 17′	60·00	3° 0′
3·40	42° 44′	6·60	25° 27′	12·00	14° 40′	70·00	2° 34′
3·60	41° 7′	6·80	24° 48′	12·50	14° 7′	80·00	2° 15′
3·80	39° 35′	7·00	24° 10′	13·00	13° 38′	90·00	2° 0′
4·00	38° 10′	7·25	23° 26′	14·00	12° 39′	100·00	1° 48′
4·20	36° 48′	7·50	22° 44′	15·00	11° 50′	120·00	1° 30′
4·40	35° 30′	7·75	22° 4′	16·00	11° 6′	140·00	1° 17′
4·60	34° 19′	8·00	21° 26′	17·00	10° 28′	160·00	1° 7′
4·80	33° 12′	8·25	20° 51′	18·00	9° 54′	180·00	1° 0′
5·00	32° 8′	8·50	20° 17′	19·00	9° 23′	200·00	0° 54′

RELATIVE WEIGHTS OF METALS TO WOOD PATTERNS

	Weight of Pattern in lbs. per Cubic Inch. No Cores.	Cast Iron. Cubic Inch = ·26 lb.	Cast Steel. Cubic Inch = ·28 lb.	Gun Metal. Cubic Inch = ·3 lb.	Aluminium. Cubic Inch = ·092 lb.
	Cubic Inch.	*Pro rata* or Relative Weights of Metals to Wood Patterns.			
Yellow pine	0·018	14·6	15·7	17	5·11
White pine	0·017	15·5	16·7	18	5·41
Baywood -	0·020	13·2	14·2	15·2	4·6
Beech -	0·025	10·5	11·3	12·2	3·68
Oak - -	0·031	8·5	9·1	9·8	2·97

IMPERIAL, BIRMINGHAM, AND AMERICAN WIRE GAUGES

Imperial.			Birmingham.			American.		
No. of Gauge.	Equivalent Diam. in Inches.	Equivalent Diam. in Mm.	No. of Gauge.	Equivalent Diam. in Inches.	Equivalent Diam. in Mm.	No. of Gauge.	Equivalent Diam. in Inches.	Equivalent Diam. in Mm.
1	·300	7·620	1	·300	7·620	1	·289	7·340
2	·276	7·010	2	·284	7·213	2	·257	6·527
3	·252	6·400	3	·259	6·578	3	·229	5·816
4	·232	5·892	4	·238	6·045	4	·204	5·181
5	·212	5·384	5	·220	5·588	5	·182	4·622
6	·192	4·876	6	·203	5·156	6	·162	4·114
7	·176	4·470	7	·180	4·571	7	·144	3·657
8	·160	4·064	8	·165	4·191	8	·128	3·251
9	·144	3·657	9	·148	3·759	9	·114	2·895
10	·128	3·251	10	·134	3·403	10	·102	2·590
11	·116	2·946	11	·120	3·047	11	·090	2·286
12	·104	2·641	12	·109	2·768	12	·080	2·032
13	·092	2·336	13	·095	2·412	13	·072	1·828
14	·080	2·032	14	·083	2·108	14	·064	1·625
15	·072	1·828	15	·072	1·828	15	·057	1·447
16	·064	1·625	16	·065	1·650	16	·050	1·270
17	·056	1·421	17	·058	1·472	17	·045	1·142
18	·048	1·218	18	·049	1·244	18	·040	1·016
19	·040	1·016	19	·042	1·066	19	·036	·9140
20	·036	·9140	20	·035	·8886	20	·032	·8124
21	·032	·8124	21	·032	·8124	21	·0284	·7213
22	·028	·7109	22	·030	·7617	22	·0253	·6126
23	·024	·6093	23	·025	·6347	23	·022	·5585
24	·022	·5585	24	·022	·5585	24	·020	·5078
25	·020	·5078	25	·020	·5078	25	·018	·4570
26	·018	·4570	26	·018	·4570	26	·016	·4062
27	·016	·4062	27	.016	·4062	27	·014	·3555
28	·014	·3555	28	·014	·3555	28	·0122	·3100
29	·013	·3300	29	·013	·3300	29	·011	·2800
30	·012	·3046	30	·012	·3046	30	·010	·2539

WHITWORTH GAS AND WATER PIPE THREADS

Pipes having an internal diameter of ⅛ in. have twenty-eight threads to the inch; an internal diameter of ¼ in. and ⅜ in., nineteen threads to the inch; an internal diameter of ½ in., ⅝ in., ¾ in., and ⅞ in., fourteen threads to the inch, and all others from 1 in. to 4 in. inclusive, eleven threads to the inch.

Internal Diam. of Pipe.	External Diam. of Pipe.	Diam. at Bottom of Thread.	Internal Diam. of Pipe.	External Diam. of Pipe.	Diam. at Bottom of Thread.	Internal Diam. of Pipe.	External Diam. of Pipe.	Diam. at Bottom of Thread.
⅛	·38	·34	1⅜	1·74	1·63	2½	3·0	2·88
¼	·52	·45	1½	1·88	1·76	2⅝	3·12	3·01
⅜	·66	·59	1⅝	2·02	1·90	2¾	3·25	3·13
½	·83	·73	1¾	2·16	2·04	2⅞	3·37	3·25
⅝	·90	·81	1⅞	2·24	2·13	3	3·48	3·37
¾	1·04	·95	2	2·35	2·23	3¼	3·70	3·58
⅞	1·19	1·10	2⅛	2·47	2·35	3½	3·91	3·79
1	1·31	1·19	2¼	2·59	2·47	3¾	4·12	4·01
1⅛	1·49	1·37	2⅜	2·79	2·68	4	4·34	4·22
1¼	1·65	1·53						

SCREW THREADS AND THICKNESSES OF WROUGHT-IRON PIPES

Briggs' American Standard

Diameter of Tube.			Thickness of Metal.	Screwed Ends.	
Nominal Inside.	Actual Inside.	Actual Outside.		Number of Threads per Inch.	Length of Perfect Screw.
Inch.	Inch.	Inch.	Inch.	No.	Inch.
⅛	0·270	0·405	0·008	27	0·19
¼	0·364	0·540	0·088	18	0·29
⅜	0·494	0·675	0·091	18	0·30
½	0·623	0·840	0·109	14	0·39
¾	0·824	1·050	0·113	14	0·40
1	1·048	1·315	0·134	11½	0·51
1¼	1·380	1·660	0·140	11½	0·54
1½	1·610	1·900	0·145	11½	0·55
2	2·067	2·375	0·154	11½	0·58
2½	2·408	2·875	0·204	8	0·89
3	3·067	3·500	0·217	8	0·95
3½	3·548	4·000	0·226	8	1·00
4	4·026	4·500	0·237	8	1·05
4½	4·508	5·000	0·246	8	1·10
5	5·045	5·563	0·259	8	1·16
6	6·065	6·625	0·280	8	1·26
7	7·023	7·625	0·301	8	1·36
8	8·000	8·625	0·322	8	1·46
9	9·000	9·688	0·344	8	1·57
10	10·019	10·750	0·366	8	1·68

Taper of conical ends 1 in 32 to axis of tube.

POWER REQUIRED FOR SOME HEAVY MACHINE TOOLS

Kind of Machines.	Size.	Material Cut.	Number of Tools.	Horse Power.		
				Motor and Shaft.	Empty Machine.	Average Cutting.
				H.P.	H.P.	H.P.
Wheel lathe - -	84 in.	Cast iron	2	...	...	6·1
,, ,, - -	84 in.	,,	2	...	...	5·1
,, ,, -	84 in.	,,	2	...	1·5	5·8
Boring mill - -	78 in.	,,	1	...	...	4·5
,, ,, - -	76 in.	,,	1	...	...	6·5
Slotting machine	36 in. × 12 in.	Wro't iron	1	1·5	1·5	5·3
Sellers planer -	62 in. × 35 ft.	,,	2	4·4	11·4	21·1
,, ,, -	62 in. × 35 ft.	,,	2	...	5·8	24·5
Planer - -	36 in. × 12 ft.	,,	2	2·7	3·0	12·5
Bement planer -	24 in. × 13 ft.	Steel	2	1·95	4·3	8·0
Sellers planer -	36 in. × 18 ft.	Wro't iron	2	3·2	4·3	16·7
,, ,, -	56 in. × 35 ft.	,,	2	4·6	9·9	13·3
,, ,, -	56 in. × 24 ft.	,,	2	4·56	6·0	16·8
Wheel lathe -	90 in.	Cast steel	2	1·43	2·1	6·34
Bement drill -	21 ft.	Wro't iron	3-$\frac{7}{8}$ in.	2·1	2·6	4·2
,, ,, -	21 ft.	,,	3-2 in.	2·1	2·6	8·0
Harrington drill -	22 ft.	,,	2-1 in.	1·1	1·45	3·7
Radial drill -	42 in.	,,	1-2 in.	0·96	1·1	2·1
Boring mill -	4 ft. 6 in.	Cast steel	1	2·1	2·4	4·6
,, ,, -	5 ft. 6 in.	Cast iron	1	1·6	2·4	4·4
Slotting machine	40 in. × 15 in.	Wro't iron	1	1·8	2·2	7·3
Shaping machine	19 in. stroke	,,	1	1·6	1·8	7·3

DECIMAL EQUIVALENTS OF MILLIMETRES AND MILLIMETRE FRACTIONS

Mm.		Inch.	Mm.		Inch.	Mm.		Inch.
1/50	=	·00079	26/50	=	·02047	2	=	·07874
2/50	=	·00157	27/50	=	·02126	3	=	·11811
3/50	=	·00236	28/50	=	·02205	4	=	·15748
4/50	=	·00315	29/50	=	·02283	5	=	·19685
5/50	=	·00394	30/50	=	·02362	6	=	·23622
6/50	=	·00472	31/50	=	·02441	7	=	·27559
7/50	=	·00551	32/50	=	·02520	8	=	·31496
8/50	=	·00630	33/50	=	·02598	9	=	·35433
9/50	=	·00709	34/50	=	·02677	10	=	·39370
10/50	=	·00787	35/50	=	·02756	11	=	·43307
11/50	=	·00866	36/50	=	·02835	12	=	·47244
12/50	=	·00945	37/50	=	·02913	13	=	·51181
13/50	=	·01024	38/50	=	·02992	14	=	·55118
14/50	=	·01102	39/50	=	·03071	15	=	·59055
15/50	=	·01181	40/50	=	·03150	16	=	·62992
16/50	=	·01260	41/50	=	·03228	17	=	·66929
17/50	=	·01339	42/50	=	·03307	18	=	·70866
18/50	=	·01417	43/50	=	·03386	19	=	·74803
19/50	=	·01496	44/50	=	·03465	20	=	·78740
20/50	=	·01575	45/50	=	·03543	21	=	·82677
21/50	=	·01654	46/50	=	·03622	22	=	·86614
22/50	=	·01732	47/50	=	·03701	23	=	·90551
23/50	=	·01811	48/50	=	·03780	24	=	·94488
24/50	=	·01890	49/50	=	·03858	25	=	·98425
25/50	=	·01969	1	=	·03937	26	=	1·02362

10 mm. = 1 centimetre = 0·3937 inch.
10 cm. = 1 decimetre = 3·937 inches.
10 dm. = 1 metre = 39·37 inches.
25·4 mm. = 1 English inch.

TAPERS PER FOOT AT CORRESPONDING ANGLES

Taper per Foot.	Included Angle.	Angle with Centre Line.	Taper per Foot.	Included Angle.	Angle with Centre Line.
1/8	0° 36′	0° 18′	1	4° 46′	2° 23′
1/4	1° 12′	0° 36′	1½	7° 09′	3° 35′
5/16	1° 30′	0° 45′	1¾	8° 20′	4° 10′
3/8	1° 47′	0° 54′	2	9° 31′	4° 46′
7/16	2° 05′	1° 02′	2½	11° 54′	5° 57′
1/2	2° 23′	1° 12′	3	14° 15′	7° 08′
3/4	3° 35′	1° 47′	3½	16° 36′	8° 18′
15/16	4° 28′	2° 14′	4	18° 55′	9° 28

WIRE GAUGE

Sizes in Decimal Parts of an Inch

No. of Wire Gauge.	American or Brown & Sharpe.	Birmingham or Stubs' Wire.	Stubs' Steel Wire.	U.S. Standard for Plate.	No. of Wire Gauge.
000000	...	...	...	·46875	000000
00000	...	...	...	·4375	00000
0000	·46	·454	...	·40625	0000
000	·40964	·425	...	·375	000
00	·3648	·38	...	·34375	00
0	·32486	·34	...	·3125	0
1	·2893	·3	·227	·28125	1
2	·25763	·284	·219	·265625	2
3	·22942	·259	·212	·25	3
4	·20431	·238	·207	·234375	4
5	·18194	·22	·204	·21875	5
6	·16202	·203	·201	·203125	6
7	·14428	·18	·199	·1875	7
8	·12849	·165	·197	·171875	8
9	·11443	·148	·194	·15625	9
10	·10189	·134	·191	·140625	10
11	·090742	·12	·188	·125	11
12	·080808	·109	·185	·109375	12
13	·071961	·095	·182	·09375	13
14	·064084	·083	·180	·078125	14
15	·057068	·072	·178	·0703125	15
16	·05082	·065	·175	·0625	16
17	·045257	·058	·172	·05625	17
18	·040303	·049	·168	·05	18
19	·03589	·042	·164	·04375	19
20	·031961	·035	·161	·0375	20
21	·028462	·032	·157	·034375	21
22	·025347	·028	·155	·03125	22
23	·022571	·025	·153	·028125	23
24	·0201	·022	·151	·025	24
25	·0179	·02	·148	·021875	25
26	·01594	·018	·146	·01875	26
27	·014195	·016	·143	·0171875	27
28	·012641	·014	·139	·015625	28
29	·011257	·013	·134	·0140625	29
30	·010025	·012	·127	·0125	30
31	·008928	·01	·120	·0109375	31
32	·00795	·009	·115	·01015625	32
33	·00708	·008	·112	·009375	33
34	·006304	·007	·110	·00859375	34
35	·005614	·005	·108	·0078125	35
36	·005	·004	·106	·00703125	36
37	·004453	...	·103	·006640625	37
38	·003965	...	·101	·00625	38
39	·003531	...	·099	...	39
40	·003144	...	·097	...	40

Metric or French Measures

Measures of Capacity

1 Litre (l.) = 1 cub. decimetre = 61·0270515 cub. in., or 0·03531 cub. ft., or 1·0567 liquid qt., or 0·908 dry qt., or 0·26427 Amer. gal.

10 Litres = 1 decalitre (dl.) = 2·6417 gal., or 1·135 pk.

10 Decalitres = 1 hectolitre (hl.) = 2·8375 bu.

10 Hectolitres = 1 kilolitre (kl.) = 61027·0515 cub. in. or 28·375 bu.

1 cub. ft. = 28·317 l., 1 gallon, Amer. = 3·785 l., 1 gallon, Brit. = 4·543 l.

Measures of Length

1 Millimetre (mm.) = 0·03937079 inch, or about $\frac{1}{25}$ inch.

10 Millimetres = 1 centimetre (cm.) = 0·3937079 inch.

10 Centimetres = 1 decimetre (dm.) = 3·937079 ,,

10 Decimetres = 1 metre (m.) = 39·37079 inches, 3·2808992 feet, or 1·09361 yards.

10 Metres = 1 decametre (dm.) = 32·808992 feet.

10 Decametres = 1 hectometre (hm.) = 19·927817 rods.

10 Hectometres = 1 kilometre (km.) = 1093·61 yards, or 0·6213824 mile.

10 Kilometres = 1 myriametre (mm.) = 6·213824 miles.

1 inch = 2·54 cm., 1 foot = 0·3048 m., 1 yard = 0·9144 m., 1 rod = 0·5029 dm., 1 mile = 1·6093 km.

Measures of Weight

1 Gramme (g.) = 15·4324874 gr. Troy, or 0·03215 oz., or 0·03527398 oz. avoir.

10 Grammes = 1 decagramme (dg.) Troy = 0·3527398 oz. avoir.

10 Decagrammes = 1 hectogramme (hg.) = 3·527398 ,,

10 Hectogrammes = 1 kilogramme (kg.) = 2·20462125 lbs.

1,000 Kilogrammes = 1 tonne (t.) = 2204·62125 lbs., or 1·1023 tons of 2,000 lbs., or 0·9842 tons of 2,240 lbs., or 19·68 cwt.

1 grain = 0·0648 gr., 1 oz. avoir. = 23·35 gr., 1 lb. = 0·4536 kg., 1 ton, 2,000 lbs. = 0·9072 t., 1 ton, 2,240 lbs. = 1·016 t., or 1,016 kg.

WEIGHTS OF ROUND AND SQUARE BARS OF STEEL IN POUNDS PER LINEAL FOOT

Diameter in Inches.	Weight of Round Bar One Foot Long.	Weight of Square Bar One Foot Long.	Diameter in Inches.	Weight of Round Bar One Foot Long.	Weight of Square Bar One Foot Long.
0	...	...	2	10·679	13·596
1/16	·010	·013	1/16	11·362	14·463
1/8	·041	·053	1/8	12·056	15·351
3/16	·093	·119	3/16	12·780	16·269
1/4	·167	·212	1/4	13·515	17·217
5/16	·261	·332	5/16	14·280	18·186
3/8	·375	·478	3/8	15·065	19·176
7/16	·511	·650	7/16	15·861	20·196
1/2	·667	·849	1/2	16·687	21·246
9/16	·844	1·076	9/16	17·533	22·327
5/8	1·043	1·328	5/8	18·400	23·429
11/16	1·261	1·607	11/16	19·288	24·561
3/4	1·502	1·912	3/4	20·196	25·714
13/16	1·762	2·245	13/16	21·124	26·897
7/8	2·044	2·603	7/8	22·072	28·101
15/16	2·347	2·988	15/16	23·041	29·335
1	2·670	3·399	3	24·031	30·600
1/16	3·014	3·838	1/16	25·041	31·885
1/8	3·379	4·303	1/8	26·081	33·201
3/16	3·765	4·795	3/16	27·132	34·547
1/4	4·172	5·312	1/4	28·203	35·914
5/16	4·600	5·856	5/16	29·304	37·311
3/8	5·049	6·428	3/8	30·416	38·729
7/16	5·518	7·025	7/16	31·558	40·177
1/2	6·007	7·650	1/2	32·711	41·646
9/16	6·519	8·300	9/16	33·894	43·146
5/8	7·051	8·978	5/8	35·088	44·676
11/16	7·604	9·681	11/16	36·312	46·236
3/4	8·178	10·414	3/4	37·556	47·817
13/16	8·772	11·169	13/16	38·811	49·419
7/8	9·388	11·954	7/8	40·096	51·051
15/16	10·024	12·760	15/16	41·401	52·713

TABLE OF DECIMAL EQUIVALENTS OF 8THS, 16THS, 32DS, AND 64THS OF AN INCH

8ths

$\frac{1}{8}$ = ·125
$\frac{1}{4}$ = ·250
$\frac{3}{8}$ = ·375
$\frac{1}{2}$ = ·500
$\frac{5}{8}$ = ·625
$\frac{3}{4}$ = ·750
$\frac{7}{8}$ = ·875

16ths

$\frac{1}{16}$ = ·0625
$\frac{3}{16}$ = ·1875
$\frac{5}{16}$ = ·3125
$\frac{7}{16}$ = ·4375
$\frac{9}{16}$ = ·5625
$\frac{11}{16}$ = ·6875
$\frac{13}{16}$ = ·8125
$\frac{15}{16}$ = ·9375

32ds

$\frac{1}{32}$ = ·03125
$\frac{3}{32}$ = ·09375
$\frac{5}{32}$ = ·15625
$\frac{7}{32}$ = ·21875
$\frac{9}{32}$ = ·28125
$\frac{11}{32}$ = ·34375
$\frac{13}{32}$ = ·40625
$\frac{15}{32}$ = ·46875
$\frac{17}{32}$ = ·53125
$\frac{19}{32}$ = ·59375
$\frac{21}{32}$ = ·65625
$\frac{23}{32}$ = ·71875
$\frac{25}{32}$ = ·78125
$\frac{27}{32}$ = ·84375
$\frac{29}{32}$ = ·90625
$\frac{31}{32}$ = ·96875

64ths

$\frac{1}{64}$ = ·015625
$\frac{3}{64}$ = ·046875
$\frac{5}{64}$ = ·078125
$\frac{7}{64}$ = ·109375
$\frac{9}{64}$ = ·140625
$\frac{11}{64}$ = ·171875
$\frac{13}{64}$ = ·203125
$\frac{15}{64}$ = ·234375
$\frac{17}{64}$ = ·265625
$\frac{19}{64}$ = 296875
$\frac{21}{64}$ = ·328125
$\frac{23}{64}$ = ·359375
$\frac{25}{64}$ = ·390625
$\frac{27}{64}$ = ·421875
$\frac{29}{64}$ = ·453125
$\frac{31}{64}$ = ·484375
$\frac{33}{64}$ = ·515625
$\frac{35}{64}$ = ·546875
$\frac{37}{64}$ = ·578125
$\frac{39}{64}$ = ·609375
$\frac{41}{64}$ = ·640625
$\frac{43}{64}$ = ·671875
$\frac{45}{64}$ = ·703125
$\frac{47}{64}$ = ·734375
$\frac{49}{64}$ = ·765625
$\frac{51}{64}$ = ·796875
$\frac{53}{64}$ = ·828125
$\frac{55}{64}$ = ·859375
$\frac{57}{64}$ = ·890625
$\frac{59}{64}$ = ·921875
$\frac{61}{64}$ = ·953125
$\frac{63}{64}$ = ·984375

RULES RELATIVE TO THE CIRCLE, ETC.

To Find Circumference—

Multiply diameter by 3·1416.
Or divide ,, ,, 0·3183.

To Find Diameter—

Multiply circumference by 0·3183.
Or divide ,, ,, 3·1416.

To Find Radius—

Multiply circumference by 0·15915.
Or divide ,, ,, 6·28318.

To Find Side of an Inscribed Square—

Multiply diameter by 0·7071.
Or multiply circumference by 0·2251.
,, divide ,, ,, 4·4428.

To Find Side of an Equal Square—

Multiply diameter by 0·8862.
Or divide ,, ,, 1·1284.
,, multiply circumference by 0·2821.
,, divide ,, ,, 3·545.

SQUARE—

A side multiplied by 1·4142 equals diameter of its circumscribing circle.
A side multiplied by 4·443 equals circumference of its circumscribing circle.
A side multiplied by 1·128 equals diameter of an equal circle.
,, ,, 3·547 ,, circumference of an equal circle.
Square inches multiplied by 1·273 equal circle inches of an equal circle.

To Find the Area of a Circle—

Multiply circumference by one quarter of the diameter.
Or ,, the square of diameter by 0·7854.
,, ,, circumference ,, ·07958.
,, ,, ½ diameter ,, 3·1416.

To Find the Surface of a Sphere or Globe—

Multiply the diameter by the circumference.
Or ,, square of diameter by 3·1416.
,, four times the square of radius ,, 3·1416.

To Find the Weight of Brass and Copper Sheets, Rods, and Bars—

Ascertain the number of cubic inches in piece and multiply same by weight per cubic inch.
Brass, 0·2972.
Copper, 0·3212.
Or multiply the length by the breadth (in feet) and product by weight in pounds per square foot.

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